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THE GENERALIZATION OF CONDITIONED RESPONSES. IV. THE EFFECTS OF VARYING AMOUNTS OF REINFORCEMENT UPON THE DEGREE OF GENERALIZATION OF CONDITIONED RESPONSES

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INTRODUCTION

Pavlov (**24**) in his discussion of generalization and differentiation has suggested two methods whereby the extent of generalization can be reduced:

"The first method consisted in repeating the definite conditioned stimulus a great number of times always accompanied by reinforcement, and the second method consisted in contrasting the single definite conditioned stimulus, which was always accompanied by reinforcement, with different neighbouring stimuli which were never reinforced" (p. 117).

But Pavlov observed that "no absolute differentiation was ever obtained by the use of the first method, even though the stimulus was repeated with reinforcement over a thousand times" (p. 117). On the other hand, it was found that "contrast by even a single unreinforced application of an

[1] This investigation was conducted in the research unit of Professor Clark L. Hull, to whom the writer wishes to express his great appreciation for assistance and encouragement.

This is the fourth in a series of studies presented as a dissertation to the Faculty of the Graduate School of Yale University in partial fulfillment of the requirements for the degree of Doctor of Philosophy in psychology, 1936. (See also **12**, **13**, **14**.)

allied stimulus, or by a number of single unreinforced applications of different members of a series of allied stimuli at infrequent intervals of days or weeks, led to a rapid development of differentiation" (p. 117).

From the standpoint of psychological theory, however, the first method is of considerable significance. If experimental work on the problem of generalization is to furnish material for the theoretical analysis of transfer of training, as Hunter (**17**) has suggested, this aspect is of pronounced importance. We already have material concerning the relationship between the degree of learning and the amount of transfer in the experiments of Wiltbank (**27**), Jackson (**18**), and others, but lack comparable studies employing conditioned response methods.

This problem is likewise important if the studies of retroactive inhibition are to be integrated with those of generalization, as has been suggested (**13**). A large number of studies have dealt with the effect of varying amounts of learning of the original material upon the amount of retroaction, (*Cf. e.g.* McGeoch, **22**). These researches are summarized by Britt (**3**). Similarly, in studying associative inhibition, Kline (**20**) has plotted the relationship between the strength of associations and the ease of association of the original elements with new materials. These problems have their counterpart in the sphere of conditioned responses in the study of the relationship between the strength of the excitatory tendencies and the degree to which such tendencies are generalized.

No direct experimental attack upon this problem has previously been made. The statement of Pavlov quoted above suggests that there is some restriction of generalization with increased reinforcement, although the differentiation is not absolute; no experimental data are presented in this connection. An interesting observation of Pavlov bears on this problem:

"It was noticed that when, after a conditioned reflex to a definite stimulus (*e.g.* a definite musical tone) had been firmly established, the effect of another closely allied stimulus (a neighbouring musical tone) was tried for the first time, the conditioned reflex which resulted from the new stimulus was frequently much weaker than that

obtained with the original conditioned stimulus. On repetition of the stimulus of the neighbouring tone, always, of course, without reinforcement, the secretory effect increased until it became equal to that given by the originally established stimulus, but subsequently on further repetition began to diminish, falling finally to a permanent zero. Thus it appeared that at first the two closely allied stimuli were discriminated straight away, but that later this discrimination for some reason disappeared, only gradually to reestablish itself and finally to become absolute" (p. 118).

The explanation advanced by Pavlov for this phenomenon is that the

"additional stimulus elicited on its first application an investigatory reflex which immediately produced an external inhibition of the conditioned reflex; on repetition the strength of the investigatory reflex rapidly diminished and the positive effect of the conditioned stimulus was temporarily restored, being later gradually suppressed by the development of internal inhibition" (p. 118).

The progressive development and subsequent decrease in generalization with varying amounts of reinforcement were studied by Beritoff (**2**). He conditioned defensive limb movements in the dog to various sensory stimuli. He reports that

"While a motor reflex to a sound of 300 vibrations per second was being established in 'Bezoukh' it could during the first day be also evoked by an unusual sound of 350 vibrations, but not by sounds of 400 to 500 vibrations. On the next day sounds of 400 to 450 vibrations evoked a reflex, but those of 500 vibrations had no effect. On the fourth day sounds of 500 to 510 vibrations excited a reflex, but those of 550 to 600 vibrations produced none. Only on the fifth day further generalization stopped, and even sounds of 500 vibrations sometimes produced no effect. In one experiment on 'Beli' the generalization of the newly-formed reflex reached its maximum on the second day. But there were also cases where the weak generalization that existed during the first few days did not increase, or even become feebler" (pp. 122–123).

The experiments of both Pavlov and Beritoff, while of considerable interest, fail to measure the degree of generalization with varying amounts of reinforcement without the complications introduced by differential reinforcement. These investigators gave reinforcement following the conditioned stimulus, but none following the allied stimuli. In the present experiments, equated groups of subjects were given varying amounts of reinforcement and the degree of generalization was then tested without differential reinforcement. The galvanic skin reaction was used as the response to permit comparison with the experiments of Pavlov on the salivary reflex and of Beritoff on motor responses and thus to establish the generality of the phenomena described by them.

Apparatus and Procedure

The same apparatus as that used in the earlier studies in this series (see 12) was employed. The unconditioned stimulus was an electric shock. The conditioned stimuli were tones produced by a beat-frequency oscillator. The response was the galvanic skin reaction. The stimuli were presented as follows: The conditioned stimulus was on for 400 milliseconds and was followed, after a pause of 95 milliseconds, by the shock which lasted 75 milliseconds.

One hundred and twenty-eight subjects, divided into four groups of thirty-two subjects each, were employed. The groups were equated on the basis of their original unconditioned responses to the shock stimuli. Groups I, II, III, and IV were given eight, sixteen, twenty-four, and forty-eight reinforcements respectively. Half of each group was conditioned to the weaker intensity of a tonal stimulus and half to the stronger. These two intensities of tone were about 150 j.n.d.'s apart. The weaker tone was 40 decibels above threshold and the stronger was 86 decibels. The frequency of the tone was 1000 cycles. The intensity of tone not used in conditioning was then employed as the allied stimulus to test for generalization.

The experimental procedure involved the following steps:

I. Test response to 40 and 86 db. tone four times each.
II. Test response to shock stimuli twice each.
III. Give the required number of reinforcements to either 40 or 86 db. tone.
IV. Test responses to 40 and 86 db. tones in counterbalanced practice order until four responses to each intensity are obtained.

With the first three groups the entire program for each subject was completed on one day. With the group given 48 reinforcements, however, it seemed advisable to divide the program into two sessions. On the first day half of the reinforcements were given. On the second, the remainder of the reinforcements and the test trials were presented. In all experiments the reinforcements and test trials were at approximately one-minute intervals.

Results

The initial equality of the four groups before conditioning is indicated by the lack of reliable difference between the responses of the different groups to the shock stimuli. The galvanic response to the shocks for the four groups was as follows:

Group I	32.8 mm
Group II	34.4 mm
Group III	32.3 mm
Group IV	33.5 mm

The responses to the two intensities of tone before conditioning likewise indicate no constant difference between the groups before conditioning:

	Intensities of Tone	
	40 db.	86 db.
Group I	1.9 mm	4.4 mm
Group II	2.1 mm	4.2 mm
Group III	1.8 mm	3.9 mm
Group IV	2.6 mm	4.4 mm

Following conditioning the test responses were obtained to the two intensities of tone in counterbalanced practice order. Detailed records of these responses to the test stimuli following eight reinforcements are given for Group I in complete form, by way of example. Table 1 presents the magni-

TABLE 1

MAGNITUDE OF GALVANIC RESPONSE (IN MM) TO CONDITIONED STIMULUS ON SUCCESSIVE TEST TRIALS FOLLOWING 8 REINFORCEMENTS

Subject	Test Trials			
	1	2	3	4
	Group Conditioned to 86 db. Tone			
I	9.2	10.0	5.1	7.1
II	15.0	14.5	14.0	11.0
III	12.2	17.0	13.5	11.5
IV	5.7	5.2	3.5	3.2
V	8.0	10.4	8.4	6.6
VI	14.1	12.2	6.8	7.9
VII	14.2	16.9	15.5	6.6
VIII	7.9	8.3	12.5	14.1
IX	12.3	6.2	5.4	9.2
X	8.6	6.5	6.0	14.9
XI	9.4	6.6	5.7	7.8
XII	10.5	12.7	10.3	10.7
XIII	9.3	11.4	8.6	9.1
XIV	10.9	8.3	13.1	10.7
XV	8.9	6.9	12.5	6.8
XVI	11.4	10.4	7.7	5.9
Mean	10.47	10.22	9.29	8.94
	Group Conditioned to 40 db. Tone			
XVII	7.9	7.3	7.3	7.5
XVIII	8.2	8.1	8.3	7.2
XIX	6.8	8.9	9.5	5.0
XX	8.9	6.9	6.0	6.0
XXI	5.0	6.9	3.3	3.9
XXII	15.9	8.1	9.5	7.7
XXIII	5.9	10.8	7.7	7.4
XXIV	8.8	7.6	6.5	8.0
XXV	6.9	5.8	8.3	6.2
XXVI	12.4	11.4	10.2	9.3
XXVII	9.3	7.7	4.9	8.5
XXVIII	10.7	8.3	6.3	3.4
XXIX	8.4	10.2	8.2	10.3
XXX	9.7	7.4	7.4	7.2
XXXI	5.5	5.4	9.1	8.7
XXXII	4.5	4.6	4.8	4.3
Mean	8.42	7.84	7.33	6.91

TABLE 2

MAGNITUDES OF GALVANIC RESPONSE (IN MM) ON SUCCESSIVE TEST TRIALS TO STIMULUS 150 J.N.D.'S REMOVED IN INTENSITY FROM CONDITIONED STIMULUS; FOLLOWING 8 REINFORCEMENTS OF CONDITIONED STIMULUS

Subject	Test Trials			
	1	2	3	4
	Generalized Responses to 40 db. Intensity (Group Conditioned to 86 db. Tone)			
I	5.4	5.1	4.0	3.0
II	7.8	7.7	3.9	4.8
III	11.3	12.0	9.2	11.3
IV	3.5	2.9	5.3	1.2
V	7.2	5.6	6.8	4.4
VI	8.4	4.8	6.8	4.6
VII	9.4	6.2	12.9	1.5
VIII	6.4	9.8	4.8	6.0
IX	9.3	5.3	3.7	6.1
X	3.4	4.7	4.8	2.2
XI	5.3	3.8	2.9	0.9
XII	3.7	6.9	5.3	3.6
XIII	3.4	4.0	3.9	2.8
XIV	6.9	6.2	6.3	1.8
XV	3.1	2.6	3.7	2.9
XVI	2.8	3.2	4.1	4.0
Mean	6.08	5.67	5.53	3.82
	Generalized Responses to 86 db. Intensity (Group Conditioned to 40 db. Tone)			
XVII	7.9	7.8	8.9	8.0
XVIII	6.9	8.0	9.5	3.1
XIX	3.8	3.2	8.8	5.0
XX	12.8	10.0	9.5	10.0
XXI	7.8	4.0	10.4	9.2
XXII	5.1	4.1	10.9	10.7
XXIII	14.6	7.1	8.8	4.1
XXIV	9.8	7.2	1.3	7.4
XXV	10.7	8.4	7.4	3.8
XXVI	8.3	6.3	6.3	4.9
XXVII	7.6	5.1	2.2	2.7
XXVIII	12.4	11.0	3.8	8.0
XXIX	8.9	7.6	5.6	6.1
XXX	5.9	4.3	4.0	3.9
XXXI	7.4	3.3	4.7	5.5
XXXII	4.0	3.2	3.6	3.1
Mean	8.37	6.29	6.61	5.97

tudes of conditioned responses on successive test trials, and Table 2 gives the same data for successive tests of the generalized responses to the stimulus 150 j.n.d.'s removed from the conditioned stimulus in intensity.

The data of Tables 1 and 2 and the corresponding results for Groups II, III, and IV, given 16, 24, and 48 reinforcements are summarized in Table 3. Here are presented the mean

TABLE 3

AMPLITUDES OF GALVANIC RESPONSE (IN MM) TO CONDITIONED STIMULUS AND TO STIMULUS 150 J.N.D.'S REMOVED IN INTENSITY FOR GROUPS GIVEN VARYING AMOUNTS OF REINFORCEMENT. EACH GROUP CONTAINS 32 SUBJECTS

Group	No. Reinforcements	Test Trials			
		1	2	3	4
	Conditioned Responses				
I.....	8	9.45	9.03	8.31	7.93
II.....	16	12.98	12.97	11.81	11.76
III.....	24	15.42	15.20	14.27	14.30
IV.....	48	16.38	16.99	15.22	15.25
	Generalized Responses				
I.....	8	7.25	5.98	6.07	4.89
II.....	16	13.12	11.82	10.94	9.87
III.....	24	16.21	12.25	10.10	10.79
IV.....	48	16.99	12.43	11.05	10.55

magnitudes of conditioned and of generalized responses following the varying amounts of reinforcement.

Acquisition of the Conditioned Galvanic Responses.—Since all of the groups were equated on the basis of their responses to the electric shock and to the tonal stimuli before conditioning, the curve of acquisition of the galvanic skin response can be plotted from the above results. The means obtained from the four test trials of the conditioned response for each of the above groups are given in Table 4. These results are presented in the form of a curve in Fig. 1. The value for the point of 0 reinforcements was obtained from the mean of the last two responses of the entire 128 subjects to the two

intensities of tone before conditioning. The curve is negatively accelerated throughout. The large initial response to the conditioned stimulus before reinforcement makes it improbable that an inflection would occur in the curve if measurements were made between 0 and 8 reinforcements.

TABLE 4

AVERAGE AMPLITUDE OF GALVANIC RESPONSE (IN MM) BASED UPON FOUR TEST TRIALS OF CONDITIONED RESPONSES FOR GROUPS GIVEN VARIOUS NUMBERS OF REINFORCEMENTS. EACH GROUP CONTAINS 32 SUBJECTS

Group	No. Reinforcements	Amplitude of Response	Probable Error $_{mean}$
I	8	8.68	0.28
II	16	12.38	0.41
III	24	14.80	0.54
IV	48	15.96	0.33

When the conditioned responses of the groups conditioned to the strong and to the weak intensity of stimuli are plotted separately, the two curves are alike, the responses to the stronger intensity being larger throughout than those to the weaker.

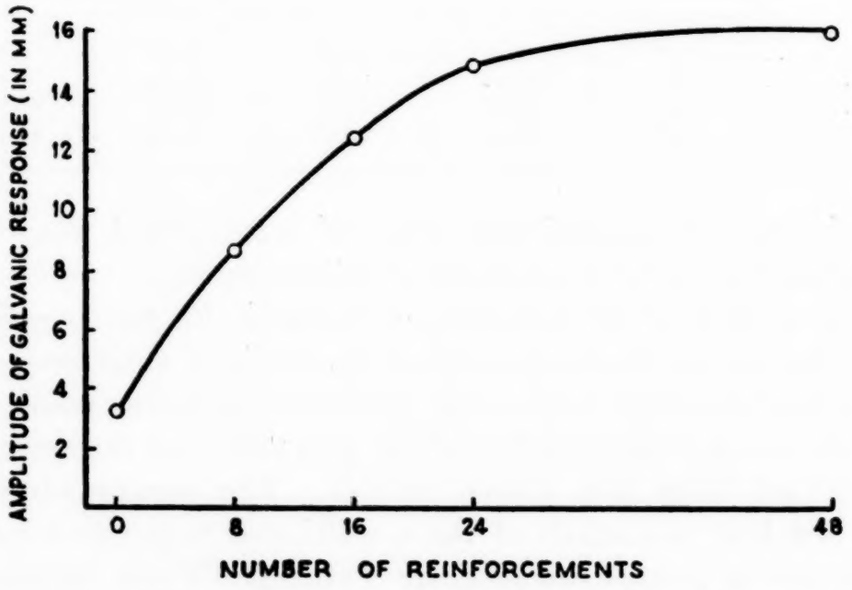

FIG. 1. Acquisition of conditioned galvanic skin response. Magnitude of galvanic response after varying numbers of reinforcements. Pre-conditioning value (0 reinforcements) based on average of all subjects; other values based upon 4 determinations on each of 32 subjects.

The results here presented, as well as those found in a preliminary experiment with varying frequencies of tone (**15**), suggest that the curve of acquisition of the galvanic skin reaction is not of the typical S-shaped variety (Hull, **16**) reported for conditioned salivary responses (Kleitman and Crisler, **19**), for conditioned knee-jerks (Wendt, **26**), and for conditioned eyelid responses in dogs (Hilgard and Marquis, **8**), monkeys (Hilgard and Marquis, **9**), and in human subjects (Hilgard, **7**, Hilgard and Campbell, **10**). Instead, the curve is of the type characteristically found for the acquisition of simple motor skills, but also obtained for conditioned respiratory responses (Garvey, **6**) and for conditioned eyelid responses with multiple stimuli (Miller and Cole, **23**).

The values used in the present determinations were the four unreinforced responses to the conditioned stimulus after varying numbers of reinforcements. It is necessary to point out, however, that these results are not uncomplicated by other factors. Of especial importance is the fact that they were not obtained in serial order, but that generalized responses were interposed. The possibility of facilitatory or inhibitory effects due to the interposed generalized responses should be checked. Experiments of the writer now in progress will afford data on the magnitude of the galvanic response with varying amounts of reinforcement without the interference of interposed responses. Campbell (**5**) reports that the "conditioned galvanic response, unlike certain other conditioned responses, appears at nearly maximum value and gradually decreases" (p. 519). The brief report of the experiment now available does not permit detailed comparison with the present results. Accessory experiments of the writer have indicated, however, that when the initial period of preconditioning testing has been omitted from the experimental procedure, a rapid negative adaptation of the galvanic response occurs which results in a decreased response to all stimuli. Previous experiments by the writer (**11**) have also indicated that prolonged reinforcement causes a decrease in the magnitude of the conditioned galvanic response similar to the effects of protracted training on other conditioned responses (*cf. e.g.* **8**, **24**).

Initial Increase of Generalization and Subsequent Restriction.—The results concerning the principal problem of the present research, the relationship between the amount of reinforcement and the extent of generalization, are given in Table 5 and Fig. 2. The ratios of the generalized responses to

TABLE 5

RATIOS (IN PERCENT) OF GENERALIZED RESPONSES TO CONDITIONED RESPONSES ON THIRD AND FOURTH TEST TRIALS FOR GROUPS HAVING VARYING AMOUNTS OF REINFORCEMENT. EACH GROUP CONTAINS 32 SUBJECTS

Group	No. Reinforcements	Mean Magnitude Generalized Responses (in mm)	Mean Magnitude Conditioned Responses (in mm)	Ratio (in Percent) of Generalized Responses to Conditioned Responses
I	8	5.48	8.12	67.48
II	16	10.41	11.79	88.28
III	24	10.45	14.29	73.11
IV	48	10.81	15.24	70.91

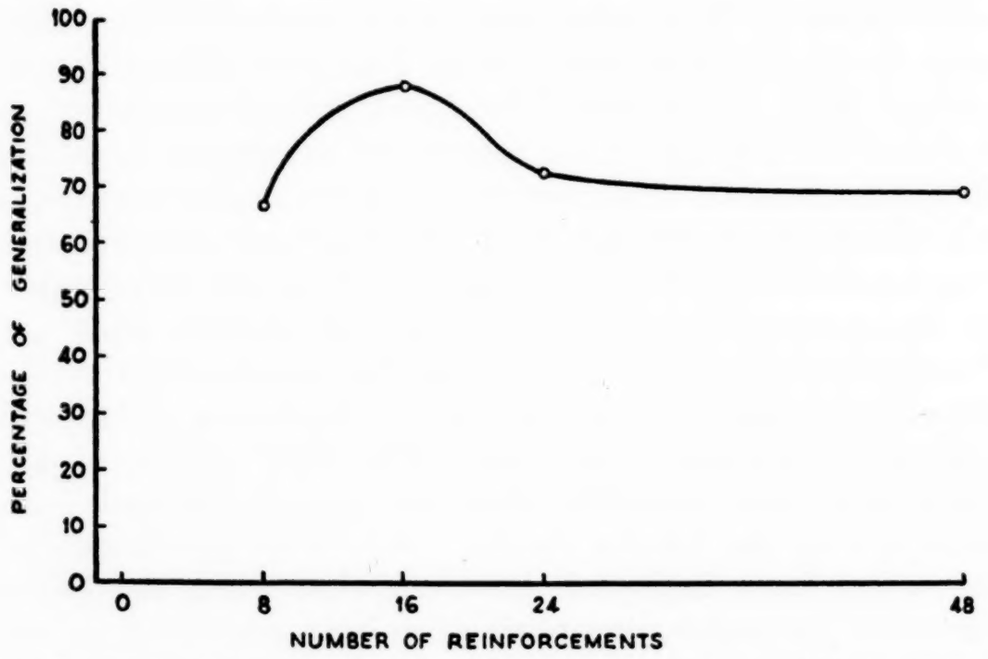

FIG. 2. Degree of generalization after varying numbers of reinforcements. Ratio of last two generalized responses to last two conditioned responses after 8, 16, 24, and 48 reinforcements. Thirty-two subjects in each group.

the conditioned responses are computed in percentage form. To avoid the interference of 'inhibition of reinforcement' (*cf.* 11 and below) which appears on the first test trials, the

mean responses on the third and fourth test trials were employed.

The present experiments give support to the statements of Pavlov and of Beritoff that before the period of differentiation there is a stage in which the degree of generalization increases. The writer has already pointed out that the results of the above named investigators were complicated by differential reinforcements.

Pavlov's explanation for the restriction of the degree of generalization at the beginning of conditioning is that the novel stimuli call forth an investigatory (what-is-it?) reflex which acts to produce external inhibition. Only with further presentations does this inhibitory effect disappear. This explanation, while probably adequate for salivary responses, does not apply in the case of the galvanic responses. Here the initial presentation of novel stimuli causes an augmentation of responses rather than a diminution. The writer (**14**) has suggested an explanation of the contradictory results on the basis of the differences in temporal relations in the two types of experimentation and in the autonomic nervous control of the two responses.

Beritoff (**2**) would explain the initial increase in the degree of generalization as a result of the increased excitability of the cortex as conditioning proceeds. Allied stimuli, subliminal at the beginning of reinforcement, would be capable of producing measurable responses with increased cortical excitability. While this theory does not explain the crucial point as to the relative effectiveness of the conditioned and of the allied stimuli, it is made plausible by a number of studies. The experiments of Switzer (**25**), Wendt (**26**), and Bernstein (**1**) demonstrate that continuous presentation of the unconditioned stimulus raises the excitability of the subject. This effect, labeled "sensitization" or "facilitation" occurs even when the conditioned and unconditioned stimuli are not paired in any regular order. If allied stimuli produce smaller responses than the conditioned stimuli throughout training, it is conceivable that an increased excitability of the subject

would permit originally inadequate stimuli to produce responses.

Beritoff explains the subsequent differentiation on the basis of a canalization of response, whereby the specific element essential for the elicitation of the reflex becomes well defined and other stimuli lose their effectiveness. This statement, while descriptive, is not explanatory. Pavlov believes that the differentiation is due to the extinction of the generalized responses to allied stimuli. While differential extinction of the conditioned and generalized responses does occur without differential reinforcement (**12**, **14**, and below), this explanation would not apply in the present experiment where no differential reinforcement has been given.

Extinction.—The results showing that a high degree of differentiation is not present on the first trials, even after a large number of reinforcements, and that the decline in the amount of generalization with added reinforcements is very gradual, are in support of Pavlov's statement that absolute differentiation cannot be produced by this method no matter how many trials are given. The relative extinction rate, on the other hand, is more rapid for the generalized responses the further the process of conditioning has advanced. This fact has been alluded to by Liddell, James and Anderson (**21**, pp. 21–22), but only incidental evidence is cited. Evidence for the rapid initial rate of extinction of generalized responses has also been given in earlier articles by the writer (**13**, **14**).

The initial rise in the extinction curve of the conditioned responses may be explained as due to a 'disinhibition' of the 'inhibition of reinforcement.' When a large number of reinforcements are given there is an adaptation by the subject to the stimulation. This effect is labeled 'inhibition of reinforcement.' Omission of the reinforcement during testing then acts as a 'disinhibitor' and the response becomes augmented. For discussion of this explanation of the rise in some extinction curves see Hovland (**11**).

The tendency for the conditioned responses to extinguish more slowly *relatively* with increased reinforcement can be seen most clearly when the responses on successive test trials

are plotted as percentages of the initial conditioned response (Fig. 3).

The results showing the more rapid extinction of generalized responses with greater amounts of reinforcement are especially interesting in the light of the findings of Brogden and Culler (4) that the higher order responses are likewise

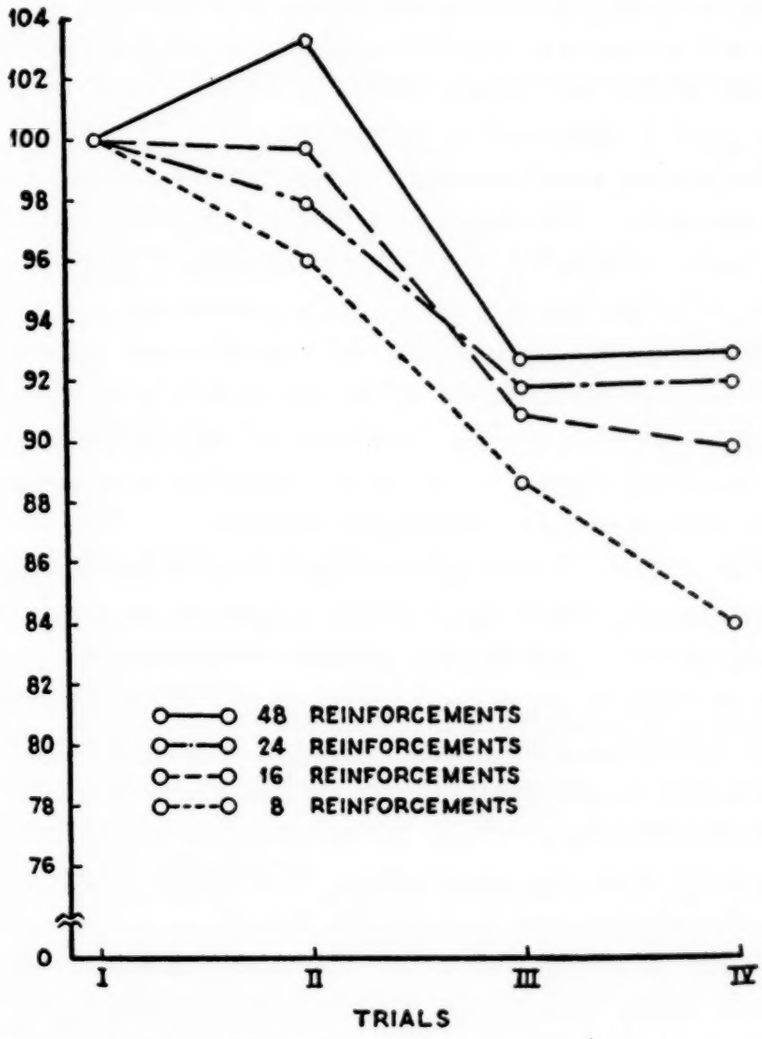

FIG. 3. Conditioned galvanic responses on successive test trials plotted as percentages of initial conditioned response for groups of subjects having 8, 16, 24, and 48 reinforcements. Each value based upon results of 32 subjects.

less stable than the primary, suggesting in both cases the relationship between biological adequacy and strength of connection. Four extinction trials are, of course, insufficient to determine adequately the stability of either the conditioned

or the generalized responses. A thorough study would also determine the number of trials required for each to be completely extinguished independently. Work on this problem is now in progress.

Summary

1. Four equated groups of 32 subjects each were given 8, 16, 24, and 48 paired presentations of tone and shock. One half of each group was conditioned to a weak tone 40 db. above threshold, while the other half was conditioned to one of 86 db. 150 j.n.d.'s removed in intensity.

2. Following reinforcement, test stimuli of both intensities were presented. The responses to the intensity used in conditioning were compared with the generalized responses to the intensity of stimulus not previously presented.

3. A curve of acquisition of conditioned galvanic skin response was plotted, based upon the means of equated groups of subjects given varying numbers of reinforcements. The curve obtained shows continuous negative acceleration, and is not of the customary S-shaped variety.

4. The ratios of the generalized responses to the conditioned responses following various numbers of reinforcements were calculated. An initial period of increasing generalization is followed by a gradual restriction. The differentiation develops following prolonged training, even when differential reinforcement is not employed. While these results, as well as the incompleteness of the differentiation which is achieved, are in accord with the *observations* of Pavlov, they cannot be explained in the present case by his *theory*.

5. There is a tendency for the conditioned responses to extinguish more slowly the further the conditioning process has advanced. Generalized responses, on the other hand, appear to decline more rapidly during testing the greater the number of reinforcements.

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References

1. Bernstein, A. L., Temporal factors in the formation of conditioned eyelid reactions in human subjects, *J. Gener. Psychol.*, 1934, 10, 173–197.

2. BERITOFF, J. S., On the fundamental nervous processes in the cortex of the cerebral hemispheres. I. The principal stages of the development of the individual reflex: its generalization and differentiation, *Brain*, 1924, **47**, 109–148
3. BRITT, S. H., Retroactive inhibition: a review of the literature, *Psychol. Bull.*, 1935, **32**, 381–440.
4. BROGDEN, W. J. AND CULLER, E., Experimental extinction of higher-order responses, *Amer. J. Psychol.*, 1935, **47**, 663–669.
5. CAMPBELL, R. K., Some difficulties in conditioning galvanic skin responses, *Psychol. Bull.*, 1936, **33**, 618–619.
6. GARVEY, C. R., A study of conditioned respiratory changes, *J. Exper. Psychol.*, 1933, **16**, 471–503.
7. HILGARD, E. R., Modification of reflexes and conditioned reactions, *J. Gener. Psychol.*, 1933, **9**, 210–215.
8. HILGARD, E. R. AND MARQUIS, D. G. Acquisition, extinction, and retention of conditioned lid responses to light in dogs, *J. Comp. Psychol.*, 1935, **19**, 29–58.
9. HILGARD, E. R. AND MARQUIS, D. G., Conditioned eyelid responses in monkeys, with a comparison of dog, monkey, and man, *Psychol. Monog.*, 1936, **47**, 186–198.
10. HILGARD, E. R. AND CAMPBELL, A. A., The course of acquisition and retention of conditioned eyelid responses in man, *J. Exper. Psychol.*, 1936, **19**, 227–247.
11. HOVLAND, C. I., 'Inhibition of reinforcement' and phenomena of experimental extinction, *Proc. Nat. Acad. Sci.*, 1936, **22**, 430–433.
12. ——, The generalization of conditioned responses. I. The sensory generalization of conditioned responses with varying frequencies of tone, *J. Gener. Psychol.*, 1937, in press.
13. ——, The generalization of conditioned responses. II. The sensory generalization of conditioned responses with varying intensities of tone, *J. Genet. Psychol.* (in press).
14. ——, The generalization of conditioned responses. III. Extinction, spontaneous recovery and disinhibition of conditioned and of generalized responses, *J. Exper. Psychol.*, 1937, **21**, 47–62.
15. ——, The effects of varying amounts of reinforcement upon the generalization of conditioned responses, *Psychol. Bull.*, 1935, **32**, 731–732.
16. HULL, C. L., Learning: II. The factor of the conditioned reflex, Chapt. 9 in *Handbk. Gener. Exper. Psychol.* (C. Murchison, Ed.), Worcester (Mass.), Clark Univ. Press, 1934, pp. 382–455.
17. HUNTER, W. S., Learning: IV. Experimental studies of learning, Chapt. 11 in *Handbk. Gener. Exper. Psychol.* (C. Murchison, Ed.), Worcester (Mass.), Clark Univ. Press, 1934, pp. 497–570.
18. JACKSON, T. A., General factors in transfer of training in the white rat, *Genet. Psychol. Monog.*, 1932, **11**, No. 1, pp. 59.
19. KLEITMAN, N. AND CRISLER, G., A quantitative study of the salivary conditioned reflex, *Amer. J. Physiol.*, 1927, **79**, 571–614.
20. KLINE, L. W., An experimental study of associative inhibition, *J. Exper. Psychol.*, 1921, **4**, 270–299.
21. LIDDELL, H. S., JAMES, W. T. AND ANDERSON, O. D., The comparative physiology of the conditioned motor reflex: based on experiments with the pig, dog, sheep, goat, and rabbit, *Comp. Psychol. Monog.*, 1934, **11**, No. 1, pp. 89.
22. MCGEOCH, J. A., The influence of degree of learning upon retroactive inhibition, *Amer. J. Psychol.*, 1929, **41**, 252–262.

23. MILLER, J. AND COLE, L. E., The influence of a 'voluntary' reaction upon the development and the extinction of the conditioned eyelid reaction, *J. Genet. Psychol.*, 1936, **48**, 405–440.
24. PAVLOV, I. P., *Conditioned Reflexes* (Trans. by G. V. Anrep), London: Oxford Univ. Press, 1927, pp. xv+430.
25. SWITZER, S. A., Disinhibition of the conditioned galvanic skin response, *J. Gener. Psychol.*, 1933, **9**, 77–100.
26. WENDT, G. R., An analytical study of the conditioned knee-jerk, *Arch. Psychol.*, 1930, **19**, No. 123, pp. 97.
27. WILTBANK, R. T., Transfer of training in white rats upon various series of mazes, *Behav. Monog.*, 1919, **4**, No. 1, pp. 65.

THE CHARACTERISTICS OF GAIT OF NORMAL MALE ADULTS *

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I. Introduction

In a recent paper by the authors a method was described for the quantitative analysis of human gait (**10**). The present paper reports the results obtained from the use of this method in the determination of the characteristics of gait of normal male adults.[1]

These results are of interest from a number of different points of view. They provide in the first place preliminary standards or norms with which may be compared the characteristics of gait occurring under conditions different from those involved in the establishment of the norms. Such norms may be used in the determination of the variations in gait which may be associated with developmental deficiencies of different kinds, or with variations in the external conditions under which an individual walks. In the second place, the characteristics of gait reported here may be regarded as providing a convenient starting point in the investigation of the course of development of gait in normal humans. The gait of normal adults may be thought of as representing the terminal or near-terminal stage of development in the activity of walking. Once the characteristics of adult gait are known, the problem of investigating its development becomes that of determining how these particular characteristics were attained in the course of motor development. The initial determination of the characteristics of adult gait thus serves to indicate the limits towards which normal development proceeds. Finally, a determination of the various properties of

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[1] Preliminary reports have been given in references **9** and **7**.

gait opens the way to the investigation of the neural mechanisms which regulate complex motor activities such as walking.

The characteristics of normal gait reported in the present paper are classified under three general headings: (*a*) Characteristics relating to the temporal and spatial pattern of the contacts made by the feet with the ground; (*b*) characteristics relating to the angular changes at various joints and the position of particular body-parts during the walking process; and (*c*) 'over-all' characteristics of the walking activity as a whole.

A brief consideration of the pattern of activity involved in walking and the need of the organism which it meets helps to indicate the significance of these different types of characteristic. Walking, as a form of locomotion, permits the organism to move from place to place with maintenance of an erect posture. This progression is made possible through the alternate contacts of the two legs with the ground at successive locations along the line of progression. The legs alternate in supporting the weight of the body, and permit the center of gravity to be successively shifted forward so as to lie over a new spatial locus. As one leg supports the weight of the body, the other moves forward through the air in order to attain a contact with the ground in advance of the supporting leg. The specification of the temporal and spatial relations of the successive contacts of the supporting legs with the ground thus furnishes a description of the final series of events by means of which the forward progression of the body is made possible. It therefore provides a natural starting place in a description of the activity of walking.

Once the temporal-spatial pattern of contacts has been determined, the question arises of the means by which it is brought about. The next step in our description is concerned therefore, with the organized pattern of movements and positions of the body-parts which occur during the course of progression. These events make possible the necessary contacts of the two legs with the ground and the maintenance of an erect posture. The second task in describing the act of walking consequently becomes that of determining the angular

changes at various joints and the positions of important body-parts as a function of time. Under this general heading might be included the angular changes at the various joints of the legs, the movements of the arms, and the positions of the trunk and head throughout the course of the walking process. In the present study, however, investigation has been limited to the sequence of angular changes at the joints of the leg, and the position of the trunk relative to the vertical at specific functional stages.

Finally, as a third section in our descriptive account of gait, certain resultant 'over-all characteristics' of gait are given, that is to say, characteristics which may be regarded as related to the activity of walking as a whole. In this class of 'over-all' properties are included length of the *period* of the successive cycles of gait, fraction of a period occupied by various stage intervals, wave length and velocity.

With respect to the systematic status of the present method of analysis of gait, it is of interest to consider the conventional differentiation of mechanics into two branches, kinematics and dynamics. Mechanics deals with the motion of masses and the effect of forces in producing or modifying these motions. Kinematics, as a branch of mechanics, is concerned with the characteristics of different kinds of motion without reference to the forces involved. Its descriptions are in terms of the three dimensions of space plus a fourth dimension, time. Dynamics, on the other hand, deals with the effect of forces in causing or modifying the motions of masses. On the basis of this distinction, our procedures for describing the characteristics of gait may be regarded as an instance of applied kinematics. The initial description of gait in terms of the concepts of kinematics provides the necessary basis for the subsequent investigation of the dynamics of gait, the determination of the forces responsible for the movements which occur during the act of walking.

II. Literature

Although there is a fairly extensive literature upon the characteristics of gait of normal adults, there have been

surprisingly few reports in which the results given are suitable as standards which may be used in determining the variations of gait characteristic of different types of subject or which may be produced by different experimental conditions. In order to be useful as standards, data on characteristics of normal gait must be accompanied by an adequate statement of the experimental conditions involved, the number and manner of selection of subjects in the normal group, and should meet, in addition, certain statistical requirements.

The description of experimental conditions should be full enough to permit later workers to plan their own investigations and evaluate their results in relation to the work and results of their predecessors. Specification of the character of the subject-group may be regarded as one phase of an adequate statement of the experimental conditions. On the statistical side, data on the limits of normal variation and statistical measures of dispersion in the normal group are essential. The specification of the limits of variation in the normal group is necessary if the data are to be used for determination of the presence of pathological deviations in individual subjects. Statistical measures of dispersion are necessary for comparison of averages obtained from groups of subjects of different types with the averages obtained in the normal group.

The following review of the literature on the characteristics of gait of normal adults will indicate the extent to which the reports made by different investigators in the past have included the material necessary for the satisfactory use of their results as standards or norms. It should be kept in mind that in many of these investigations the authors were not specifically concerned with the provision of norms but were concerned with other kinds of problems. In our review of the literature on the various properties of gait, we may use as a basis the classification of properties represented in Tables 1 through 4.

(*a*) *Temporal Pattern of Foot-contacts*

Reports on the temporal relations of the foot-contacts or steps have been given by Weber, E. and W., 1836 (24), Carlet, 1872 (2), Marey, 1879–1894 (12, 13, 14),

TABLE 1

TEMPORAL-SPATIAL PATTERN OF FOOT CONTACTS IN GAIT OF NORMAL MALE ADULTS

Characteristics	Left Leg (L)				Right Leg (R)				L–R			
	Lower Limit	Upper Limit	Ave.	SD	Lower Limit	Upper Limit	Ave.	SD	Lower Limit	Upper Limit	Ave.	SD
A. Temporal relations												
1. Duration in sec. of:												
Overlap	.06	.19	.13	.04	.13	.19	.15	.03	.00	−.07	−.02	.03
Single support	.41	.56	.48	.05	.44	.53	.48	.03	+.06	−.06	.00	.03
Recovery stroke	.44	.53	.48	.04	.41	.56	.49	.05	+.03	−.06	−.01	.02
Ground stroke	.69	.88	.74	.07	.69	.88	.75	.07	+.03	−.03	.00	.02
2. Fraction of period in:												
Overlap	.05	.14	.10	.03	.10	.16	.12	.02	.00	−.06	−.02	.02
Single support	.36	.45	.40	.03	.36	.42	.39	.02	+.07	−.05	+.01	.03
Recovery stroke	.36	.42	.39	.02	.34	.43	.39	.03	+.03	−.03	.00	.02
Ground stroke	.58	.64	.61	.02	.57	.66	.61	.03	+.03	−.03	.00	.02
B. Spatial relations	Step ending at Stage 1				Step ending at Stage 3				1–3			
1. Length of step in cm.	31.0	45.0	39.7	5.1	30.0	45.0	37.9	6.3	+6.0	−2.0	1.8	2.34
2. Width of base in cm.												
In single step	+.42	+7.00	+3.07	3.17	+.50	+9.00	+3.96	3.76	+.12	−3.00	−.89	1.42
	1 and 3											
Ave. width of 1 and 3	+.50	+7.50	+2.98	3.31								
Ave. width of base / Standing height	.0027	.0041	.0175	.0172								
Ave. width of base / Ave. length of step	.016	.181	.076	.072								
3. Angle of foot-axis in degrees	+2.1	+6.4	+3.8	1.9	+1.4	+5.2	+3.5	1.5	+2.9	−3.0	+0.2	2.9

TABLE 2A

CHARACTERISTICS OF ANGULAR MOVEMENTS AT JOINTS OF LEGS IN GAIT OF NORMAL MALE ADULTS [2]

Characteristics	Left Leg (L)				Right Leg (R)				L–R			
	Lower Limit	Upper Limit	Ave.	SD	Lower Limit	Upper Limit	Ave.	SD	Lower Limit	Upper Limit	Ave.	SD
1. Extent of joint movement												
Hip												
Max.	+30.0	+33.0	+31.3	1.2	+28.5	+36.0	+32.1	2.1	+4.5	−5.0	−0.8	2.4
Min.	−22.0	−6.0	−14.5	4.7	−18.5	−7.0	−12.8	3.7	+9.0	−2.5	+1.8	4.4
Range	36.0	55.0	45.8	5.4	40.0	49.5	44.8	3.1	9.0	−4.0	+1.0	4.1
Knee												
Max.	+61.0	+76.5	+68.2	4.5	+65.0	+74.0	+69.5	2.9	+6.0	−7.0	−1.3	4.0
Min.	0.4	+4.0	+0.4	1.3	0.0	+10.0	+1.9	3.0	0.0	−6.0	−1.5	1.9
Range	57.0	76.5	67.8	5.3	58.0	74.0	67.6	4.5	+8.0	−4.0	+0.3	3.7
Ankle												
Max.	+5.0	+15.0	+11.2	3.1	+6.0	+13.5	+10.0	2.4	+5.0	−1.0	+1.2	1.9
Min.	−9.0	−4.0	−6.2	1.5	−10.0	−3.5	−6.1	1.9	+2.0	−2.5	+0.1	1.5
Range	12.0	22.0	17.4	3.1	12.0	20.0	16.1	2.7	+3.5	−3.0	+1.3	2.1
2. Form of curves												
Hip												
No. of waves ampl.	1	1	1	0.0	1	1	1	0.0	0.0	0.0	0.0	0.0
Flex.	36.0	55.0	45.8	5.4	40.0	49.5	44.8	3.1	+9.0	−4.0	+1.0	4.1
Exten.	39.0	54.0	45.9	4.8	42.0	49.0	45.0	2.1	+8.0	−5.0	+1.0	3.4
Flex.—exten.	+3.0	−4.0	−0.1	2.1	+5.5	−4.0	−0.2	2.5	+4.0	−5.0	+0.1	2.7
Exten./flex.	.98	1.09	1.01	.05	.89	1.10	1.01	.05	+.11	−.08	.00	.06
Phase of max.	.27	.39	.35	.05	.26	.39	.31	.04	+.13	−.05	+.04	.05
Fraction of period	.90	1.00	.98	.04	.95	1.00	1.00	.02	.00	−.09	−.02	.03
Knee												
No. of waves												
A wave ampl.	2	2	2	0.0	2	2	2	0.0	0.0	0.0	0.0	.00
Flex.	57.0	75.0	66.8	5.2	56.0	73.0	68.5	5.1	+4.0	−11.0	−1.8	4.1
Exten.	56.0	76.5	65.6	5.6	61.0	71.5	66.7	3.8	+6.0	−7.0	+1.2	4.0
Flex.—exten.	+6.0	−3.5	+1.2	2.6	+8.0	−7.0	+1.9	4.8	+14.0	−7.5	+1.0	6.7
Exten./flex.	.91	1.06	.98	.04	.89	1.13	.97	.07	+.11	−.15	+.01	.08

[2] All properties in section 1 of Table 2A, and the following properties in section 2 of this table are measured in angular degrees: amplitude of flexion, amplitude of extension, and flexion minus extension for each of the waves considered.

TABLE 2*A*—*Continued*

Characteristics	Left Leg (L)				Right Leg (R)				L–R			
	Lower Limit	Upper Limit	Ave.	SD	Lower Limit	Upper Limit	Ave.	SD	Lower Limit	Upper Limit	Ave.	SD
Knee (continued)												
Phase of max.	.22	.45	.36	.09	.28	.43	.37	.04	+.11	−.15	.00	.08
Fraction of period	.44	.68	.60	.10	.53	.70	.61	.05	+.13	−.19	−.01	.10
B wave ampl.												
Flex.	1.5	26.0	9.8	7.6	3.0	20.0	13.0	4.6	+6.0	−9.5	−3.2	5.7
Exten.	2.0	25.0	11.3	6.6	3.0	20.0	15.0	5.5	+7.0	−12.0	−3.7	5.9
Flex.—exten.	+2.0	−6.0	−1.6	2.4	+1.0	−8.0	−2.3	3.0	+5.0	−5.0	+0.1	2.8
Exten./flex.	.82	2.67	1.42	.65	.91	1.57	1.16	.23	+1.23	−.32	+.26	.55
Phase of max.	.67	.83	.75	.05	.67	.82	.74	.05	+.10	−.05	+.01	.04
Fraction of period	.23	.56	.42	.10	.32	.45	.39	.04	+.19	−.13	+.03	.10
Ankle												
No. of waves												
A wave ampl.	2	2	2	0.0	2	2	2	0.0	0.0	0.0	0.0	0.0
Flex.	4.0	15.5	10.3	4.2	6.0	14.0	9.6	3.4	+6.0	−5.0	+0.7	3.4
Exten.	7.0	14.0	9.5	2.6	5.0	11.0	8.8	1.8	+6.5	−2.0	+0.8	2.7
Flex.—exten.	+7.0	−4.0	+0.8	3.2	+4.0	−2.0	+0.9	2.6	+7.0	−3.0	−0.1	1.1
Exten./flex.	.52	2.00	1.05	4.3	.71	1.70	1.09	3.2	+.71	−.82	−.13	.43
Phase of max.	.11	.26	.20	.04	.06	.33	.24	.08	+.20	−.16	−.03	.10
Fraction of period	.33	.47	.41	.05	.28	.50	.41	.07	+.16	−.11	.00	.09
B wave ampl.												
Flex.	10.0	20.5	15.2	3.1	12.0	17.0	14.6	2.3	+5.0	−2.5	+1.2	2.4
Exten.	8.0	19.5	15.7	4.1	11.0	21.0	15.8	3.1	+4.0	−3.0	−0.1	2.0
Flex.—exten.	+4.0	−4.5	+.02	3.1	+2.0	−3.0	−1.3	3.1	+4.0	−2.5	−1.5	3.7
Exten./flex.	.73	1.36	1.00	.22	.88	1.31	1.08	.16	+.30	−.23	−.08	.15
Phase of max.	.61	.86	.80	.07	.67	.83	.77	.05	+.16	−.13	+.03	.31
Fraction of period	.55	.72	.61	.07	.55	.65	.60	.05	+.09	−.10	.00	.07

TABLE 2*B*

POSITION OF TRUNK RELATIVE TO VERTICAL AT VARIOUS STAGES OF GAIT

Characteristics	Lower Limit	Upper Limit	Ave.	SD
Trunk relative to vertical in degrees				
Stage: 1	+5.5	− 3.0	+0.6	3.1
2	−0.5	− 7.0	−3.8	2.2
3	−0.5	−10.0	−4.9	3.7
4	+1.5	− 7.5	−2.0	2.7
1	+3.5	− 7.0	−1.5	3.5

TABLE 3

OVER-ALL CHARACTERISTICS OF GAIT OF NORMAL MALE ADULTS

Characteristics	Lower Limit	Upper Limit	Ave.	SD
Period in sec.	1.13	1.38	1.23	.10
Fraction of period for stage interval:				
1 to 2	.18	.25	.22	.02
2 to 3	.25	.34	.28	.03
3 to 4	.18	.26	.23	.03
4 to 1	.25	.34	.28	.03
1 to 3	.47	.50	.49	.01
3 to 1	.50	.53	.51	.01
Wave length (step at 1+step at 3+2 ft. length) in cm.	112.0	146.0	129.6	11.9
Velocity $\frac{\text{wave length}}{\text{period}}$ in cm. per sec.	81.2	121.0	106.3	13.5

Comte and Regnault, 1896 (3), Fischer, 1900 (5), Vierordt, 1881 (25), and Mommsen, 1932 (15).

With respect to method, the Webers, Vierordt, and Mommsen recorded kymographically the times at which electrical contacts were made as a result of the feet coming in contact with the ground. Carlet and Marey used a similar method except that changes in air pressure in specially constructed shoes served as an index of the sequence of steps instead of electrical contacts. Comte and Regnault, and Fischer obtained their data by chronophotographic procedures: successive pictures were taken at short intervals of the individual walking. This procedure may be regarded as the predecessor of the motion picture technique.

In none of these investigations except that of Vierordt, who examined two adult subjects, and Comte and Regnault, who used one subject, have we been able to find definite statements of the number of subjects used in the experimental groups. Nor do any of the authors mentioned give data on the limits of normal variation or other measures of dispersion. Quantitative results given consist of estimates of average values, or reports of arithmetical means alone.

TABLE 4

COMPARISON OF MAXIMUM AMPLITUDE OF MOVEMENT AT JOINTS OF LEG DURING NORMAL GAIT AND MAXIMUM CAPACITY FOR VOLUNTARY MOVEMENT AT THESE JOINTS

Joint-movement	Comparison of Averages of Normal Group of Subjects					Comparison of Specific Measurements of Individual Represented in Fig. 1		
	1 Max. Ampl. during Gait		2 Max. Capacity		3 Utilizat. Ratio in Percent	4 Max. Ampl. during Gait	5 Max. Capacity	6 Utilizat. Ratio in Percent
	Arith. Mean	σdist.	Arith. Mean	σdist.				
Right hip								
Vent. flex	32°	2.1°	97.8°	17°	33	30°	105°	28
Dors. flex	12.8°	3.7°	48.4°	12.9°	26	17°	56°	30
(rel. to 180° angle)								
Right knee flex	69.5°	2.9°	126.6°	6.7°	55	68°	136°	50
(rel. to 180° angle)								
Right ankle								
Dors. flex	10°	2.4°	36.8°	6.6°	27	11.5°	30°	38
Plant. flex.....	6.1°	1.9°	28.2°	7.4°	22	5.0°	27°	19
(rel. to 90° angle)								

Durations and temporal relations of weight bearing by different parts of the feet have been investigated by Carlet, 1872 (**2**), Marey, 1879–1894 (**12, 13, 14**), Vierordt, 1881 (**25**), Mommsen, 1932 (**15**), and by Schwartz, Heath and their collaborators, 1932–1936 (**16–21**). Since our own investigations have not been concerned with these particular characteristics of gait, a detailed summary of the results of the workers just mentioned is not necessary. The most thorough investigations of 'weight bearing' by different parts of the foot have been those of Schwartz and his colleagues.

(*b*) *Spatial Relations of Foot-contacts*

(1) *Length of Step.*—Reports upon the length of the step during normal gait have been made by the Webers, 1826 (**24**), Vierordt, 1881 (**25**), Comte and Regnault, 1896 (**3**), and Fischer, 1900 (**5**). Comte and Regnault and Fischer used a chronophotographic method of recording; Vierordt's method involved the use of marking styluses attached to the shoes, one at the heel and one at each side of the foot in the metatarsal region. Comte and Regnault used one adult subject in their investigation; Vierordt apparently used two subjects, and Fischer used 103 subjects. Only in the case of Fischer's investigation is a report of range of normal variation given. The other investigators mentioned only approximate averages or arithmetical means.

(2) *Width of Base.*—Vierordt, 1881 (**25**), is the only author we have found who reports on width of base during walking of normal adults. His method involved the use of marking styluses attached to the shoes, as mentioned above. Two adult subjects were examined. Quantitative results are given in terms of arithmetical means alone.

(3) *Angle of the Foot-axis.*—Reports on angle of foot-axis in the gait of normal adults have been made by Vierordt, 1881 (**25**), and Dougan, 1924 (**4**). Vierordt ob-

tained records by means of marking styluses as already indicated. Dougan took records on paper of footprints made by subjects wearing hob-nail shoes. Vierordt apparently used two adult subjects and reports the arithmetical mean of measurements made. Dougan used in his experimental group a total of 229 subjects, 103 being high school students, and 126 university students. His quantitative results are given in terms of arithmetical means for right and left sides, and upper and lower limits of the distributions. Measures of dispersion such as average deviations or standard deviations are not given.

(c) *Movements of Particular Body Parts*

(1) *Movements at Joint of Legs*

(*a*) Comte and Regnault, 1896 (3), reported on *extent of joint movement* at the hip, knee, and ankle during the gait of normal adults. A chronophotographic method was used for recording changes in the positions of the body-parts as viewed from the side. The procedure for measuring angles at the joints is not stated. One adult subject was used. Quantitative results on extent of joint movement consist of statements of 'approximate average extent' in degrees. The 'extent of movement' represented by the results refers to the total angle lying between the two extreme positions of a given joint. The specific interest of the authors of this report was in the determination of the effect of different speeds and of flexed position of the limbs on the characteristics of gait and fatigue.

Investigations of changes in *position of the legs* and its parts have been made by Marey, 1879–1885 (12, 13), Fischer, 1895 (5), and Kraus, 1923 (11). Marey's and Braune and Fischer's methods were chronophotographic. Marey made a series of profile photographs of the subject at regular intervals. In his later studies, tights with lines outlined upon them were worn by the subjects to indicate the direction of the axes of body parts. Braune and Fischer attached long Geisler tubes to the subjects for a similar purpose. The circuit through the tubes was closed and opened at intervals of .0383 sec. Kraus's method involved the taking of motion picture records of the subjects viewed from the sides. These pictures were then projected as stills and the outlines of the legs in any particular frame were traced. No statement was found of the number of subjects used in Marey's or Braune and Fischer's studies. Kraus apparently used one subject in his investigation, but he too fails to state so explicitly.

The results reported by Marey consist of descriptive statements accompanied by reproductions of illustrative series of records to show changes in position of the parts of the body during walking. Braune and Fischer measured in *linear units* the changes in position in both horizontal and vertical directions of points located at the hip, knee, and ankle joints. The results of such measurements of successive records were represented by curves showing vertical and horizontal oscillations of the points in question throughout the course of gait. Tables are given of average results obtained in a number of successive trials for sample subjects, but no statistics are given on the range of variation found among different normal subjects.

Kraus's results, like those of Marey, are mainly descriptive, and are presented in conjunction with outline tracings of the positions of the legs as found in successive frames. Kraus was primarily concerned with a theoretical discussion of the neurological mechanisms involved in gait.

(2) *Position of Trunk*

Reports on changes in position of the trunk as determined from lateral views have been made by Braune and Fischer (1), and by Comte and Regnault (3). The method

in both cases was chronophotographic. Comte and Regnault used one subject; the number used by Braune and Fischer was not stated. The measurements of Braune and Fischer were in terms of the linear displacements in horizontal and vertical directions of a point located on the shoulder. Comte and Regnault reported upon the angular inclination of the trunk relative to a horizontal line. The quantitative results of Braune and Fischer consist of arithmetic means of the total distance in cm. between extreme positions on both sides of the vertical reference line; Comte and Regnault give approximate averages of their measurements. Neither group of authors gives statistics on the variability found among different normal subjects.

(3) *Other Body-parts Investigated*

A number of body-parts not considered above nor included in our table of norms have been investigated by some authors. Thus Marey investigated variations in the height of the pelvis as determined from back views of the subjects, and Braune and Fischer have investigated oscillations in vertical level above the ground of the head and trunk as determined from lateral and front and back views. Weber, E. and W. (**24**), Marey (**12, 13, 14**), and Braune and Fischer (**1**), have also investigated changes in linear position of different parts of the arms by means of methods similar to those they used for the legs.

(*d*) *Over-all Characteristics*

Velocity of gait in normal adults has been investigated by Weber, E. and W., 1836 (**24**), and Mommsen, 1932 (**15**). The method used by these authors involved the making of kymographic records of electrical contacts. The size and nature of the experimental groups were not indicated. Results were reported in terms of arithmetical means. Indications of the dispersion of measures were not given. It is to be noted, however, that in the investigations of the Webers, velocity of gait had the logical status of a variable or a parameter whose effect on other properties of gait was being investigated. Mommsen, on the other hand, wished to determine the velocity of free or natural gait in normal and pathological subjects.

The above survey of the literature shows that in only two of the investigations considered, that of Fischer on length of step, and of Dougan on angle of foot-axis have data been given on the range of variation that may occur among a group of normal subjects. In none of the investigations reviewed have statistical measures of dispersion been given such as are desirable in comparison of average measures obtained on subjects of a normal or standard group with those obtained on other types of subject. In the case of many of the investigations, there is a similar dearth of data on the number and nature of the subjects used in the investigation. In certain studies in which number of subjects is specified, results are available on but one or two sample subjects. There is need therefore of additional investigations of the characteristics of normal gait that shall be free from limitations of the sort

mentioned. The present study represents an attempt to meet this need in a provisional way by investigation of a sample group of normal male adults. Some of the properties examined have been investigated previously by means of other methods as pointed out above. Other properties, such as most of those listed in Table 2*A* have not been investigated previously.

III. Conditions of the Investigation

A. Subjects

The characteristics of normal gait reported below were determined from measurements made with a group of 10 mentally normal male adults without any known signs of motor disorder. The characteristics of this group of subjects were as follows: (*a*) in height, the subjects ranged between 5 ft. 4 in. and 6 ft. 1 in. with an average height of 5 ft. 9 in.; (*b*) in weight, the subjects ranged from 120 lbs. to 172 lbs. with an average weight of 145 lbs.; (*c*) in age, the subjects ranged from 21 years to 33 years with an average age of 27 years. With respect to general physical condition the subjects were all in good health and suffered from no known motor or neuromuscular disorders. All subjects were right-handed as determined by means of Lauterbach's inventory for the determination of handedness.

The subjects were all assumed to fall within the normal intelligence range on the basis of records of educational background and occupation. With respect to education, all subjects had graduated from high school and had had at least a year of college work. With respect to occupation, 5 subjects were on the professional staff of the laboratory, 4 were teachers in the educational department, and one was an engineer. We consider it relevant to indicate the intellectual status of the subjects in view of the fact that one of our interests in establishing a set of norms for gait was to provide standards that may be used in investigation of the comparative development of gait in mentally defective subjects of various types with mentally normal subjects. Such investigations are of interest in view of numerous indications that deficiencies in development of other bodily functions may be associated with mental deficiencies of different types.

B. Procedure

The characteristics of gait reported below are based on frame-by-frame measurements made upon motion picture records taken of the individual subjects walking at a moderate rate and without shoes. The details of the procedures and the definitions of the various properties of gait examined have for the most part been given in an earlier paper (**10**). A brief summary of the various terms used in the tables is given below.

(1) *Total Over-all Characteristics of Gait*

To facilitate the description of gait, four temporal landmarks are picked out and designated as Stage 1, 2, 3, and 4 respectively.

Stage 1 stands for the moment when the left heel first strikes the floor, Stage 3 when the right heel first strikes the floor, and Stages 2 and 4 the intermediate positions when the center of gravity of the body lies directly over one leg serving as the base of support. These stages are referred to as functional stages of gait. The sequence of events occurring at any joint between two successive occurrences of Stage 1 or any other salient point is referred to as a *cycle*. The duration of a cycle equals a *period*. The distance covered between two recurrences of Stage 1 is called the *wave length*. The *velocity*, in cm. per second, is readily determined as the ratio of the wave length to the period.

(2) *Temporal Relations of Foot-contacts*

The term *ground-stroke* refers to the interval during which a given leg is in contact with the ground. The term *overlap* refers to the time interval following immediately after the beginning of Stages 1 or 3 during which both legs are in contact with the ground, the rear leg not losing contact for a short interval after the forward leg strikes the ground. The term *recovery stroke* refers to the interval during which a given leg is swinging forward over the ground in preparation for the following ground stroke. Duration of the various intervals are given both in absolute terms and relative to the period or duration of an entire cycle.

(3) *Spatial Relations of Foot-contacts*

In Section B of Table 1 are considered the spatial relations between the feet when they are both in contact with the ground. The *length of the step* is measured between the toe of the rear foot and the heel of the forward foot. The *width of the base* is measured transversely between the centers of the two heels. The *angle of the foot-axis* represents the angle made by the foot-axis with the direction of progression when a given foot is in contact with the ground.

(4) *Angular Changes at the Joints*

The properties listed in Table 2A were determined on the basis of measurements made upon successive motion picture frames of angular position of hip, knee, and ankle oints. These data were then represented graphically as illustrated in Fig. 1 to show the changes in the joints as a function of time in relation to the various functional stages of gait and to the temporal sequence of contacts with the ground of the foot as a whole and of heel and toe separately. Under the heading *extent of joint movement* the angular positions corresponding to the highest and lowest points of a curve throughout a cycle are specified. Under *range* is specified angular difference between these two positions. The figures given for *maximum* and *minimum* extent of joint movement in the table are expressed in relation to the angle at the joint represented by the base lines of Fig. 1. Thus, for movements at the hip, the base line corresponds to an angle of 180°. The joint angle corresponding to the highest (and lowest) point of the curve during a cycle is recorded as the difference between this angle and 180°. If the sign is positive, the point is above the base line and represents the extent to which the hip has flexed ventrally beyond the 180° position. If the sign is negative the point in question is below the base line and represents the extent to which the hip has become extended or flexed dorsally beyond the 180° position. A similar procedure is followed in the case of the knee and ankle joints. The base line of the curve for the knee joint is 180°, and in the case of the ankle joint is 90°.

Under the heading *form of curve* various characteristics are given which provide an empirical description of the form of the curve representing movement at each of the three joints of the leg. To facilitate this description a single cycle of each curve is

first labeled in accordance with the number of waves appearing throughout a cycle. A single wave is represented as occupying the interval between two successive troughs on the curve. In Fig. 1 we find that but one wave occurs throughout one cycle of movement at the hip joint, two waves at the knee joint, and two waves at the ankle joint. In the case of the knee, the wave beginning between Stages 4 and 1 on the curve is called the *A* wave, and the next wave in the cycle, the *B* wave. In the case of the ankle joint, the wave beginning between Stages 1 and 2 is called the *A* wave, and the next wave in the cycle the *B* wave. Since curves of the same general type as are shown in Fig. 1 were found for all subjects making up our group of normal subjects, it was possible to establish quantitative norms of the characteristics of the various waves for the group as a whole. For each wave present in a cycle, the following characteristics were determined: the amplitude in degrees of the rising and falling limbs of the wave, the ratio of amplitudes of rising and falling limbs, the differences of these amplitudes, the *phase* of the maximum point of the wave, and the fraction of the total period occupied by the wave. The phase at any point of the wave is defined as the fractional part of the cycle that has passed by the time that point on the wave has been reached, the cycle being regarded here as starting with the trough at the beginning of the *A* wave.

For each of the characteristics listed in the tables and for the left and right legs separately, when appropriate, are given the arithmetical mean, the upper and lower limits, and the standard deviation of the distribution of measures for the group of normal subjects examined. In addition, to show the relations of a given characteristic on the two sides of the body, the differences of the measures on the two sides are also stated. It should be borne in mind that the values recorded are based on the relations found in each of the individual subjects. That is to say, the differences between the measures on the two sides of the body are determined separately for each of the subjects and the arithmetic means and other statistics for the group are then calculated in the usual way.

In connection with the properties which involved both sides of the body, it was sometimes arbitrary which of two measures was to be recorded in the column for the left or right side. Thus, in the specification of the length of the step, the step ending with the contact of the left heel with the ground (Stage 1) is recorded in the column for the left leg, and the other step in the cycle in the column for the right leg.

IV. Results

Tables 1 through 4 provide a summary of the characteristics of normal gait as determined under the conditions of

the present study. Figure 1 shows a sample record of the nature of the graphical records of gait obtained for each subject. Graphs of this sort were obtained for both left and right legs.

V. Comment

A. The Use of the Tables as Norms

The tables of the properties of gait given above represent characteristics of gait of a sample group of normal male adults. In the use of these tables as norms and in comparing the characteristics of gait of other types of individuals it will obviously be necessary for the measurements to be made under the particular conditions used in the establishment of the norms. These conditions are stated in detail in a previous paper (**10**).[3] It should be borne in mind, too, that the norms given here are to be regarded as but first approximations. The limiting values found for the various properties of gait in our normal sample may be extended somewhat upon examination of a much larger group of subjects.

B. Variability of Gait and its Factors

In the tables given of the normal characteristics of gait, we find the range of normal variation specified in terms of the standard deviation of the distribution, and in terms of the upper and lower limiting measures. It is desirable to keep in mind the kinds of factors that may contribute to this variability. They may be classified as of three kinds: (*a*) Variable or accidental errors of measurement of the characteristics of gait of individual subjects, (*b*) variability in the gait of a given subject as it occurs at different times, and (*c*) individual differences in gait among different subjects. The measures of variability given in our tables may be regarded as a resultant of the operation of all three of these factors.

The extent to which it is necessary to factor out the contributions of these separate factors to the total or resultant variability found for a group of subjects will differ with the particular problem under investigation. Thus, if one is comparing the average

[3] In Table 4, page 132 of the paper mentioned (**10**), the following correction should be made. The figure for measured angle at the hip in rows 1 and 2 of column 2 should read 120.5° instead of 125.5°.

values of the characteristics of two groups of subjects, such as mentally normal subjects and feeble-minded subjects of a particular kind, it is sufficient to take into account the total dispersion of the measures for each group as dependent upon all three of the factors mentioned above. If, however, one wishes to determine whether the gait of a particular individual, such as a crippled person who has been undergoing some form of treatment, falls outside the normal range it is necessary to make more than one determination of the characteristics of that individual's gait, and so obtain a measure of its variability which depends on both accidental errors of measurement and variations in the subject's gait as it occurs at different times. Finally, if one wishes to determine to what extent the variation found to occur in different samples of the gait of a particular individual are due to real variations in gait, it will be necessary to compare the magnitude of the variations found at different times with the experimental error of measurement. The particular determinations of variability to be made will thus depend in every instance on the question being investigated.

The magnitude of the accidental errors of measurement to which the method of analysis of gait used here is subject has been given for a number of properties in a previous paper (10). Preliminary determinations of the variability which may occur in the gait of individual subjects from time to time has been made in the case of normal male adults and will be reported in a later paper. A study of the variability occurring at early developmental stages of gait in young children is under way. The indications are that the variability in different properties of gait steadily decreases during the course of development. The magnitude of individual differences in gait among different adult subjects is a problem of considerable interest in itself and will be susceptible to more precise determination after determinations of the combined effect of errors of measurement and of variations in the gait of a subject at different times have been made.

With respect to the question of precision of measurement, attention may be called here to the errors involved in determination of temporal pattern of gait. It will be recalled that the successive pictures used as a basis of analysis were photographed at intervals of 1/16 of a second. Consequently any of the points in the graphs at which a change in direction is indicated—such as the instant at which ground stroke or recovery strokes begin, or the instant at which maximum angular position is reached for a given joint, may be in error by amounts up to 1/16 of a second. The magnitude of such errors might obviously be reduced by an increase in the rate at which the successive frames are photographed.

C. Some Noteworthy Features of Adult Gait

Attention is called in this section to certain features of gait that seem to merit special comment. These comments are concerned for the most part with the relations between the curves showing angular changes at the joints of the leg and the graphs representing the temporal pattern of foot-contacts which occur during walking. The relations pointed out are apparent in the graphs of gait of all of the subjects in the normal group, and may be illustrated by reference to the sample record of one subject given in Fig. 1. The curves of

this figure should be examined in connection with the descriptions given below.

1. *Point in the Recovery Stroke of Maximum Ventral Flexion of the Hip.*

In our preliminary characterization of gait, we have described it as an activity in which the weight of the body is alternately supported on opposite legs with the non-supporting leg moving forward simultaneously through the air on a recovery stroke. On the basis of such a statement of the bare essentials of gait, one might expect that maximum ventral flexion of the thigh with the trunk would occur at Stage 1, for the left leg, and at Stage 3 for the right leg, the instants at which the leg in question is thrust forward to make renewed contact with the ground. An examination of the records shows that maximum flexion does not occur at these points. In the case of the right leg, for example, as illustrated in Fig. 1, maximum ventral flexion at the hip occurs well before the occurrence of Stage 3. In the particular curve illustrated it occurs even before the mid-point of the recovery stroke, rather than at its end. Once this fact has been noted, it becomes understandable when one considers the movements necessary to bring the forward swinging leg in contact with the ground. The leg first swings forward in the air, but must then drop to the ground in order to make contact. If the trunk remains approximately erect, the dropping of the leg must lead to an increase in the angle at the hip, that is to say, a return of the leg from the position of maximum ventral forward.

2. *Waves Present in the Curve Showing Angular Changes at the Knee Joint.*

The curve for the knee joint shows two waves, each representing a sequence of flexion and extension occurring during a single cycle. The period of most marked flexion occurs during the *A* wave. This wave is confined largely to the recovery stroke of the leg, though it begins somewhat before the start of the recovery stroke. The probable function of the extreme degree of flexion represented by the

maximum point of the *A* wave is to make possible the clearing of the ground by the foot, as the foot swings forward as a result of ventral flexion at the hip.

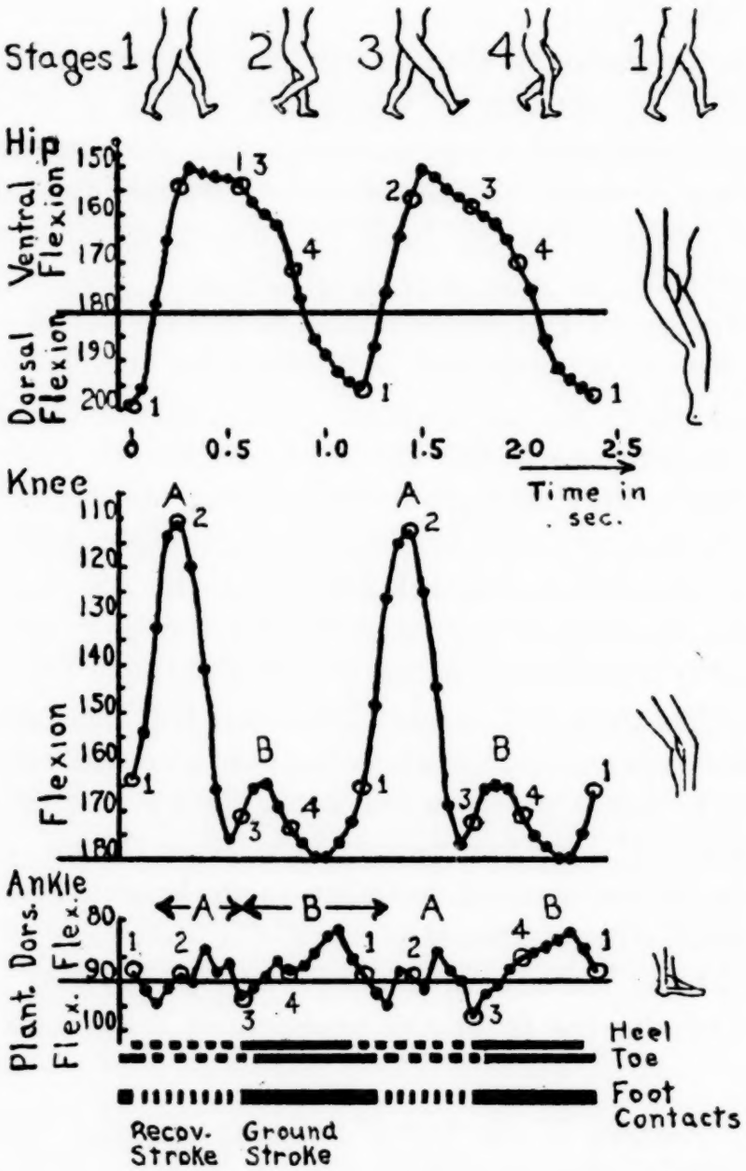

FIG. 1. Graphs showing angular changes (in degrees) at joints of right leg and contacts of feet with ground as a function of time in gait of normal male adult.

Following the *A* wave of the knee joint, there occurs a second period of flexion and extension at the knee joint as represented by the *B* wave. The maximum point of this wave is, however, much lower than the maximum point of the *A* wave. This *B* wave begins just before the forward swing-

ing leg makes contact with the ground, continues after the foot has struck the ground, reaches a maximum relatively early in the ground stroke, and then falls more slowly to a minimum position as the knee joint moves through a period of extension.

Conventional characterizations of gait in which the knee is spoken of as fixed during its weight supporting period do not suggest the existence of a secondary period of flexion and extension such as is represented by the *B* wave. Nor was the phenomenon noted in preliminary direct observations of the movements occurring during the activity of walking. It may, however, be observed even in direct examination of gait if one is predisposed to look for it as a result of graphical records.

The question may be raised of the physiological mechanism responsible for the *B* wave. In this connection a hypothesis of Sherrington's concerning the functional significance of the stretch reflex is directly relevant. Sherrington, noting that the stretch reflex is most marked in the antigravity muscles, suggested that the stretch reflex of the limb extensors is a basic factor in the static reflex of standing, as a result of which the weight of the body is supported in opposition to gravity (**23**, **6**). Elsewhere, in describing the flexion and extension phases of the reflex act of stepping in the spinal or decerebrate animal, Sherrington points out that the muscles in which reflex tonus is most marked (for example, in decerebrate rigidity) are precisely those which are in active contraction in the extensor phase of the step, when the weight of the body is being supported by the legs in contact with the ground (**22**). The implication made therefore is that the stretch reflex of the limb extensors is a fundamental factor in the extension or support phase of the stepping reflex of the animal preparation.

Our detailed description of the changes occurring at various joints of human subjects provides the opportunity of testing the correctness of Sherrington's hypothesis in the case of the gait of the human adult. As already noted, in the case of all the subjects of our normal group, the *B* wave was found to occur regularly in movements at the knee joint. This

phenomenon can be plausibly interpreted as dependent on the operation of the stretch reflex, and to that extent provides concrete evidence of the applicability of Sherrington's hypothesis to human gait.

It may be supposed, for example, that the period of flexion at the knee, represented by the rising limb of the *B* wave, is brought about by the action of gravity, when the weight of the body is transferred to the leg at the beginning of its ground stroke. This flexion of the knee will stretch the quadriceps muscles and hence bring into operation the stretch reflex. The quadriceps will, consequently, contract and produce extension at the knee, as represented by the downward limb of the *B* wave. This explanation is in need of more precise testing, but provides a plausible working hypothesis of the mechanisms on which the *B* wave at the knee depend.

The hypothesis outlined has indicated the probable functional role of the extension represented by the falling limb of the *B* wave—the support of the body weight in opposition to the force of gravity. The flexion of the knee joint represented by the rising limb of the *B* wave possibly has as its function, in addition to its provision of the stimulus necessary for the subsequent operation of the stretch reflex, the provision of a spring-like action which partially absorbs the jar to the body produced when the forward leg strikes the ground in front.

(3) *The Waves Occurring at the Ankle Joint during One Cycle of Gait.*

The curve representing angular changes at the ankle joint during a cycle of gait, shows that in the case of this joint as in the case of the knee joint, two major waves of movement occur. The *A* wave begins during the recovery stroke of the leg and is wholly confined to this period. The *B* wave, on the other hand, starts with the ground stroke of the leg, lasts through the entire ground stroke and terminates early in the following recovery stroke.

A consideration of the relation of these waves to the temporal pattern of foot-contacts suggests the probable

function of the waves in the act of walking, and the factors which determine the turning points in the curve.

The dorsi-flexion of the ankle represented by the rising limb of the *A* wave, begins shortly after the beginning of the recovery stroke. It may be plausibly regarded as contributing to the clearing of the ground by the foot. After the leg has swung past its mid-recovery position, the direction of movement at the ankle changes to plantar flexion as the leg is swung forward for its next contact with the ground. According to the sample curve, the end of the period of plantar flexion is reached just as the heel strikes the ground in front.

The *B* wave in the curve of Fig. 1 begins as the right heel strikes the ground in front. The increasing dorsi-flexion represented by the upward limb of the *B* wave may be regarded as due to the increasingly acute angle forward made by the lower leg with the ground. This continued tilting of the leg forward permits the weight of the body to be shifted forward, the foot, planted on the ground, serving as a base of support and a pivot. The maximum position of dorsi-flexion is reached, according to the graph of Fig. 1, just before the heel starts to rise from the ground. A period of dorsi-flexion at the ankle then takes place as represented by the downward limb of the *B* wave. It is apparent on mechanical grounds that the period of dorsi-flexion at the ankle can occur at this part of the cycle only as a consequence of the raising of the heel from the ground. It is therefore necessary to suppose that the maximum point of the *B* wave occurs at the instant before the heel is raised from the ground. According to the graph the heel is not represented as raised from the ground until an interval of 1/16 of a second has elapsed after the maximum point of the *B* wave has been passed. But it must be borne in mind that the motion picture records were taken at 1/16 of a second intervals. The 1/16 of a second interval between the two points must therefore be regarded as an artifact dependent on the fact that the pictures were not photographed at a greater rate of speed.

The graph represents the dorsi-flexion at the ankle as continuing even after the toe of the rear leg has been lifted

from the ground, and has thus begun the recovery stroke. This continued dorsi-flexion might possibly be considered as analagous to the 'follow through' of movements which occur in certain athletic activities, as in the swing of a tennis racket after the ball has been struck. It seems likely that this continued dorsi-flexion at the ankle after the 'push-off' of the toe from the ground would be even more marked in vigorous or fast walking.

(4) *The Smoothness of the Curve of Joint-movement.*

A fact of interest in the curves for the hip and ankle joint is the marked smoothness of contours, even though the curves have not been artificially smoothed. This characteristic of the curve stands in contrast to an appreciably greater jaggedness or roughness of the curves which later studies have shown to be present in the curves at very early developmental stages of gait, and in the gait of spastic subjects. The relatively greater 'roughness' of the curve for the ankle must be regarded as due in part to the smaller range through which this joint moves and the increased difficulty of measurements.

(5) *The Relation between the Maximum Amplitude of Movements Occurring during Gait and the Maximum Capacity for Movement.*

In connection with any complex motor activity, such as walking, which involves the coöperation of many body-parts it is of interest to examine the extent to which the full capacity for movement is utilized in the movements of the various parts coöperating. Thus we may compare the maximum range of amplitude of movement at hip, knee, and ankle joints which occur in the course of walking with the maximum range of voluntary movements which is possible at these joints. Such a comparison indicates that the individual in walking utilizes but a small fraction of his full capacity for movement. Data on the maximum amplitude of voluntary movement possible at various joints were available from a study of the authors carried out in connection with a different problem (**8**). This latter study was carried out upon the

same group of subjects that served as the experimental group of the present investigation.

Table 4 indicates the extent to which the maximum amplitude of movement at various joints of the leg during gait approach the maximum amplitude of voluntary movement of which the joint in question is capable. In Columns 1, 2, and 3, this comparison is made on the basis of the arithmetical means obtained for the entire group of subjects; in Columns 4, 5, and 6 a similar comparison is made of the measurements obtained on the particular subject whose curves of gait are represented in Fig. 1. The angles specified in the various columns are measured in relation to the base lines of the curves of Fig. 1. That is to say, the angles corresponding to these base lines are taken as zero. The utilization ratio specified in Columns 3 and 6 is defined as the ratio of the maximum amplitude of movements at a joint during walking to the maximum capacity for voluntary movement at that joint, expressed in per cent. The ratios given in Columns 3 and 6 indicate that but a small percentage of the maximum amplitude of movement possible is actually utilized. This result suggests that subjects affected by a neuro-muscular disorder which involves a decrease in maximum possible amplitude of movement at the joints, as in spasticity, need not, on the basis of limitation of maximum amplitude alone be prevented from carrying out in normal fashion various complex motor activities necessary in everyday life. The fact mentioned also suggests that precise measurement of the maximum capacity for movement in various joints might provide a means for early diagnosis of neuro-muscular disorders which were slowly developing, but were not yet extreme enough to be apparent in most of the habitual motor-activities.

VI. Summary

(1) The aim of the present study was to determine the characteristics of gait of a sample group of normal male adults by means of a method for analysis of gait recently described by the authors.

(2) The results are presented in the form of tables of norms to facilitate their use in investigations of the deviations that may occur in individual subjects and in groups of subjects of different types from those examined here.

(3) The properties of gait investigated fall under three main headings: (*a*) properties relating to temporal-spatial pattern of foot-contacts; (*b*) properties relating to changes in position of particular body-parts, measured in degrees; and (*c*) over-all properties of gait relating to the walking activity as a whole.

(4) Certain noteworthy features of gait exhibited by the graphical records are discussed in terms of their neurological basis and the role they play in the organized activity of walking.

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References

1. Braune, W. and Fischer, O., Der Gang des Menschen, *Abh. d. math.-phys. Klasse d. könig sachs. Gesselsch. d. Wiss.*, 1895, **21**, No. 4.
2. Carlet, G., Étude sur la locomotion humaine, *Ann. Sci. Naturelles*, 1872, **5**, 1–92.
3. Comte, C. and Regnault, F., Etude comparative entre la methode de marche et de course dite de flexion et les allures ordinaires, *Arch. physiol. nor. et pathol.*, 1896, **8**, 380–389.
4. Dougan, S., The angle of gait, *Amer. J. Phys. Anthropol.*, 1924, **7**, 275–279.
5. Fischer, O., Der Gang des Menschen, *Abh. d. math.-phys. Klasse d. könig sachs. Gesellsch. d. Wiss.*, 1895, **25**. The original of this paper was not available. A summary of its results was found in Vierordt, H. (**26**), pp. 438, 441.
6. Fulton, J. F., *Muscular Contraction and the Reflex Control of Movement*, Baltimore, 1926, 372 f.
7. Glanville, A. D. and Kreezer, G., Quantitative studies of human gait and its development, *Psychol. Bull.*, 1936, **33**, 609 (abstract).
8. Glanville, A. D. and Kreezer, G., The maximum amplitude and velocity of joint movements in normal male human adults, *Human Biology*, 1937, **9**, 197–211.
9. Kreezer, G., Motor studies of the mentally deficient: quantitative methods at various levels of integration, *Train. Sch. Bull.*, 1935, **32**, 129.
10. Kreezer, G. and Glanville, A. D., A method for the quantitative analysis of human gait, *J. Genet. Psychol.*, 1937, **50**, 109–136.
11. Kraus, A. M., The difference between a muscular and a neuromuscular interpretation of walking, *Arch. Neurol. & Psychiat.*, 1923, **9**, 184–207.
12. Marey, E. J., *La Machine Animale*, Paris, 1879.
13. Marey, E. J., *Developpement de la methode grafique d'emploi de la photographie*, Paris, 1885.

14. MAREY, E. J., *Le mouvement*, Paris, 1894. (None of Marey's books were accessible to us. Reports of his results were found in LUCIANI, L., *Human Physiology* (English translation by Welby), 1915, **3**, 115–118, 122–127.)
15. MOMMSEN, F., Über den zeitlichen Ablauf der Schrittfolge und der Fussabwicklung beim Gehen und ihre Bedeutung fur die Analyse und Begutachtung von Gangstörungen, *Zsch. f. orthop. Chir.*, 1932, **57**, 1–18.
16. SCHWARTZ, R. P. AND VAETH, W., Method for making graphic records of normal and pathological gait, *J. Amer. Med. Assoc.*, 1928, **90**, 86–89.
17. SCHWARTZ, R. P. AND HEATH, A. L., Pneumographic method of recording gait, *J. Bone & Joint Surg.*, 1932, **14**, 783–794.
18. SCHWARTZ, R. P., HEATH, A. L. AND WRIGHT, J. N., Electrobasographic method of recording gait, *Arch. Surg.*, 1933, **27**, 926–934.
19. SCHWARTZ, R. P., HEATH, A. L., MISIEK, W. AND WRIGHT, J. N., Kinetics of human gait, *J. Bone & Joint Surg.*, 1934, **32**, 343–350.
20. SCHWARTZ, R. P., HEATH, A. L. AND MISIEK, W., The influence of the shoe on gait, as recorded by the electrobasograph and slow-motion pictures, *J. Bone & Joint Surg.*, 1935, **33**, 406–418.
21. SCHWARTZ, R. P., TRAUTMANN, O. AND HEATH, A. L., Gait and muscle function recorded by the electrobasograph, *J. Bone & Joint Surg.*, 1936, **18**, 445–454.
22. SHERRINGTON, C. S., Postural activity of muscle and nerve, *Brain*, 1915, **38**, 196 f.
23. SHERRINGTON, C. S., Problems of muscular receptivity, *Nature*, 1924, **113**, 732, 892–894, 924–932.
24. WEBER, E. AND WEBER, W., *Mechanik der Menschlichen Gehwerkzeuge*, Göttingen, 1836.
25. VIERORDT, H., *Der Gang des Menschen*, Tübingen, 1881.
26. VIERORDT, H., *Anatomische, physiologische und physikalische Daten und Tabellen*, Jena, 1906. (Especially pp. 438–441.)

BRAIN POTENTIALS AND THE TEMPORAL COURSE OF CONSCIOUSNESS

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Introduction

The psychologist should be interested in brain potentials mainly because of their possible relation to, and clarification of, mental life. He may begin safely with two assumptions: first, that the higher mental processes are identified with cortical function; and second, that the electrical potentials known as the Berger rhythm are of cortical origin. The question is, how are brain potentials and mental processes related.

It has been widely reported that effective stimuli, such as light, depress or obliterate entirely the rhythmical cortical potentials. Concentrated thinking, as on an arithmetical problem generally reduces the size of the potential waves. It may also increase their frequency. It appears then that, in some way, psychological factors and the electrical activity of the cortex are related. Are brain potentials and mental processes both manifestations of the same underlying activity of the brain? When, at any given moment, one obtains a report of another's immediate awareness and a record of his brain potentials, is he obtaining essentially two indications of the same basic function? It occurred to me, as undoubtedly it has to many others, that the electroencephalographic technique used in conjunction with standard psychological procedures, ought to assist in the answer to this fundamental question.

This study represents an attack on the more striking relationships existing between electrical potentials from the brain and conscious states. It will certainly leave for future investigations a detailed analysis of further possible interrelationships.

Problem and Procedure

Only one aspect of the brain waves was given primary consideration, namely size. Frequency was given secondary consideration. The problem was mainly then, what is the relationship, for a given person, between the size of his brain waves and the temporal course of consciousness as revealed by his introspective reports. At a certain moment the subject was given a signal (the spoken word *now*) to report what conscious state, if any, the signal interrupted. He had been instructed previously to relax and permit his mind to 'wander.' He was told particularly not to direct the stream of consciousness and to report exactly what was in his mind at the signal. Experimenter and subject could converse by means of an intercommunicating system between rooms.

As the subject lay with his eyes closed on a cot in a dark and quiet room, his brain potentials were recorded in another room by an ink-writing undulator. The experimenter could see the brain potentials as they were being recorded. At certain times, when the waves were relatively small or large, or of average size the experimenter would say *now* and press simultaneously a key to operate a signal marker on the brain wave record and would then write down as fully and accurately as possible the subject's report.[1]

The subject could not know what sort of brain waves were appearing in the record. Neither could the experimenter know what was going on in the subject's mind at the time he signalled for the report. He asked very few questions and when he did he scrupulously avoided leading questions.

For each subject a scale was constructed from measurements of the extent of a fair sampling of his brain waves. On the basis of this scale, waves at and just preceding the inter-

[1] The possibility of evaluating the brain waves to include an additional category, 'absent,' was seriously considered. In some records, for all practical purposes, there were no waves. One may say, however, that there is rarely, or never, a complete lack of brain potentials from the living, mature brain during the waking state. An absence of waves may mean that, at certain times, our present amplifiers are not sufficiently sensitive and free of thermal agitation noise to detect them. It was decided, therefore, to use one category, 'small,' to include those periods when on the records the waves were either absent or relatively small.

ruptions were classified as small, average, and large. The brain wave records were evaluated twice, once with reference to the introspective reports and once without reference to either the introspective reports or to the first evaluation. There was a practically perfect agreement between the two readings.

Eight persons from the department of psychology served as subjects; four staff members, two post-doctorate students, one graduate student, and one undergraduate student. There were 6 men and 2 women. Each subject had a large percentage of alpha waves. The potentials were led off by means of surface electrodes, one attached to the left occiput and the other to the lobe of the left ear.

Results

Five hundred and eighty-three introspective reports were secured (Table I). They were considered as denoting mainly

TABLE I

The Number of Times a Given Mental Process is Associated with Small Average, and Large Brain Potentials

Mental Process	Size of Brain Potentials						Total Number
	Small		Average		Large		
	Percent	N	Percent	N	Percent	N	
Vis. image of light	93	46	7	3	0	0	49
Vis. image of objects	66	114	20	35	14	23	172
Mental blankness	1	1	9	11	90	106	118
Abstract thinking	21	21	33	29	46	42	92
Kinesthetic sensation	56	29	29	15	15	8	52
Organic sensation	34	6	33	6	33	6	18
Mixed images	39	7	39	7	22	4	18
Mental effort	67	10	20	3	13	2	15
Auditory image	36	5	57	8	7	1	14
Kinesthetic image	18	2	36	4	46	5	11
Anticipation	45	4	45	4	10	1	9
Verbal idea	88	7	12	1	0	0	8
Itching	0	0	75	3	25	1	4
Anxiety	100	3	0	0	0	0	3
Total		255		129		199	583

imagery, sensation, mental effort, abstract thinking, and mental blankness. The visual images were divided into two groups, those in which light or color was prominent and those

of objects. The subjects reported 'seeing' light-flashes, black and gray bars, balls of light, lightning, and rich colors. Such images were grouped under visual images of light. It is possible that some of these were photomata in which the sensory element was maximal and the associational element minimal.

The subjects reported also 'seeing' persons, books, houses, roads, and such like. These were grouped under visual images of objects.

These two groups deserve separate treatment because of the repeatedly observed effect of a light stimulus on brain potentials and because as we were obtaining the records it seemed that the visual images of light were more consistently associated with small brain waves than were visual images of objects. The data justify this division.

Auditory images were of instrumental music, voices, and noises. Under mental effort were listed reported attempts to refrain from thinking, to ignore external and internal stimuli, to keep from falling asleep, and to relax. The category, kinesthetic sensation, was used to denote awareness of tensions in the legs, arms, neck, back and face; and the category, organic sensation, bladder tensions, pressures in chest, nausea, and dizziness.

The term abstract thinking may be a questionable one. It was used to include such reports as 'organizing my lecture,' 'questioning the advisability of using tests,' 'considering my grounding in experimental psychology,' 'hoping certain things aren't true,' and 'wondering if brain waves are related to personality.' Such reports were considered under abstract thinking if the subject failed to report, either spontaneously or upon questioning, any type of imagery. We do not wish to argue the question of imageless thought. All we wish to say is that if there were any images they were not of sufficient clearness to be detected.

The term mental blankness may be a questionable one also. To the experimenter's *now* the subject would say 'nothing,' or "I've forgotten," or 'nothing in particular.' Again, all we wish to say is that if there were images they were not sufficiently clear to be noticed or remembered.

Mixed images were generally visual and auditory although occasionally kinesthetic images were also reported along with the other two types. Kinesthetic images were expressed as 'feeling myself bending over,' or 'felt as though I were walking.' Under anticipation were included such reports as "I was waiting for your signal." Verbal idea was expressed by the subject talking to himself. One subject reported the sensation of itching, mainly in one hand; and another subject, feelings of anxiety about appointments.

TABLE II

DIFFERENCES IN THE PERCENTAGES OF TIMES A GIVEN MENTAL PROCESS IS ASSOCIATED WITH SMALL, AVERAGE, AND LARGE BRAIN POTENTIALS. THE SIZE OF THE WAVE MORE FREQUENTLY ASSOCIATED WITH A GIVEN MENTAL PROCESS IS LISTED FIRST

	Diff. in Percent	CR
Vis. image of light		
Small vs average	.86	16.7
Small vs large	.93	25.5
Average vs large	7	1.9
Vs. image of objects		
Small vs average	.46	9.7
Small vs large	.52	11.6
Average vs large	6	1.5
Mental blankness		
Large vs average	.81	21.2
Large vs small	.89	30.1
Average vs small	8	2.9
Abstract thinking		
Large vs average	.13	1.8
Large vs small	.25	3.7
Average vs small	.12	2.7
Kinesthetic sensation		
Small vs average	.27	2.9
Small vs large	.41	4.8
Average vs large	.14	1.7
Mental effort		
Small vs average	.47	3.0
Small vs large	.54	3.6
Average vs large	7	0.5
Organic sensation		
Small vs average	1	0.1
Small vs large	1	0.1
Average vs large	0	0.0
Mixed images		
Small vs average	0	0.0
Small vs large	.17	1.1
Average vs large	.17	1.1

The tables reveal the fact that visual images, kinesthetic sensations, and mental effort are associated with relatively small, while mental blankness and abstract thinking are associated with relatively large, brain potentials. Organic sensations and mixed images are not related significantly to any one size of wave. Because of their infrequency of occurrence, the other mental processes were not treated quantitatively. From the few reports we have, verbal ideas and anxiety are associated mainly with small waves. Frequently the small waves were more rapid than the typical 10 per sec. rhythm.

Discussion

On the basis of studies on both animals and human beings, it may be supposed that the cortical cells have a tendency to beat spontaneously and synchronously under conditions of minimal stimulation. This collective action displays itself in relatively large and regular electrical potentials of 10 per sec. Such potentials may thus be considered as representative of a basic cortical equilibrium, and to afford a standard of comparison. Disturbances in these potentials may be taken to indicate disturbances in the basic condition of the cortex. A break-up of the collective action does not mean a falling off in cortical activity, for it must be remembered that persistent activity, if not synchronous, would give rise to smaller and sometimes more rapid oscillations. The failure of the large waves shows merely that the collective beat has ceased.

We have become accustomed to the autogenous rhythmic activity of the heart and to the persistent rhythm of the respiratory center. Many of us have considered the cerebral cortex a great silent network of neurones activated only in response to stimulation. It appears now that we will have to accept the fact that there is a constant background of pre-existing and possibly autogenous activity in the brain and that the end-result of stimulation represents the interaction of incoming and central activity.

It may be disturbing to some of us that for a relatively large share of the time mental blankness and abstract thinking

are alike in that both are coexistent with a basic cortical equilibrium as expressed in the collective action of the cortical cells. However, in reviewing those processes (sensation,

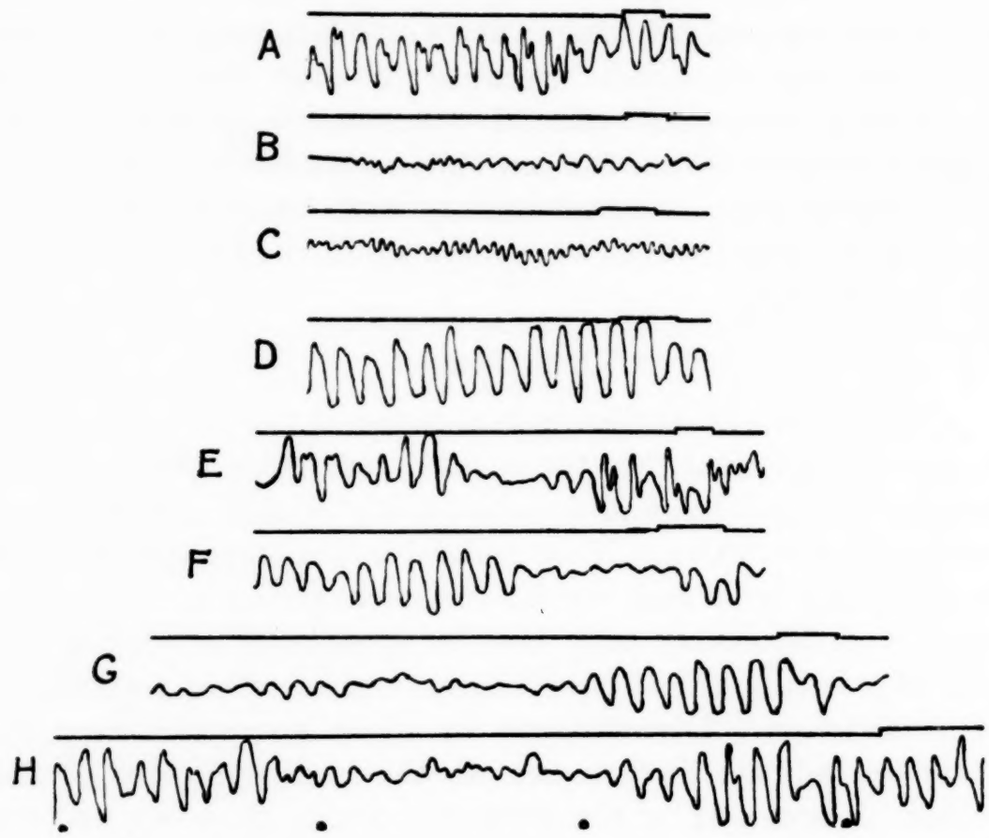

FIG. 1. Records showing relationships between brain waves and the temporal course of consciousness. The signal word *now* indicated by upward deflection of signal line in upper right hand corner of each record. Time in sec. marked off at bottom of last record. *A* = mental blankness and *B* = visual image of object for the same subject. *C* = visual image of object. This record shows the small, rapid, and regular oscillations characteristic of certain subjects for visual images. *D* = visual image of object. This record is a striking exception to the general rule that visual images are associated with small brain waves. For *E*, the subject reported mental blankness at the signal, but the 'flashing into mind' of a visual image of an object just before the signal. *F* = visual image of object 'flashed' into mind. For *G*, the subject reported that he had been hearing a song and at the signal he was passively listening for it and recalling the pleasant feeling he always has when he hears the song on the radio. For *H* the subject reported 'nothing' at the signal but the 'flashing into mind' of a visual image of an object just before the signal.

image) which disturb this basic equilibrium it may be noted that they represent, or act as, more or less discrete stimuli which call attention to themselves. All through brain

potential work it has appeared that factors effective in disturbing the alpha rhythm are those which focus consciousness. It is doubtful if much focusing of consciousness occurs in the mental process expressed in such reports as 'considering my grounding in experimental psychology.' Some of the time abstract thinking was associated with smaller and faster waves. Here there must have been a more discrete factor present in the form of a sensation or an image.

There is a suggestion then that large regular brain potentials indicative of a state of cortical equilibrium represent a generalized psychic activity while a break-up of this collective action into more rapid and irregular oscillations of much smaller amplitude represents a relatively high degree of specificity in psychic activity.

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VINCENT CURVES OF CONDITIONING

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Hunter (**6**) has presented Vincent curves of conditioning based on the acquisition by rats of a simple locomotor habit. These curves lack the initial positive acceleration and the later negative acceleration reported by most writers who have constructed curves of acquisition of conditioned responses (Hilgard, **3**). They differ from the only other Vincent curve of conditioning in the literature, Hull's reconstruction of Kleitman and Crisler's data (**5**, p. 425). This curve was positively accelerated throughout. The form of the curve is shown by Hunter to be dependent on the stringency of the criterion of mastery adopted. If a more severe criterion is set (in terms of the number of consecutive trials on which conditioned responses occur), the practice curve is found to rise more rapidly than if a less severe criterion is used. Because of this, Hunter doubts the validity for conditioning of the Kjerstad-Robinson Law which states that the form of the Vincent curve for memorization is independent of the amount of material to be learned (*e.g.*, McGeoch, **7**).

Our results (**4**) showing the course of acquisition of conditioned eyelid responses for college students appeared at the same time as Hunter's paper. The curves we presented were trial-by-trial averages of responses from three groups of subjects, each subject within each group having an individual curve similar in form to that of the group to which he was assigned. Within the 50 reinforcement trials of the first day of conditioning, some of these were positively accelerated throughout (23 subjects), others showed double inflection (17 subjects), and still others were predominantly negatively

accelerated (11 subjects). It was pointed out, however, that initial positive acceleration could be inferred for each group. Within the second day of conditioning, all groups showed negative acceleration. The examination of individual curves leaves no doubt that for these subjects the form of the curve of conditioning is typically doubly inflected, positively accelerated at first, negatively accelerated later. This is the reasonable expectation because no conditioned responses ordinarily appear in the first few trials, and because an upper limit is reached in later trials (Hilgard, **2**, p. 12).

It has seemed desirable to us to recast our data in the form of Vincent curves in order to determine whether or not the differences between our results and Hunter's are real or merely due to differences in the treatment of data.

The grouping of data may conceal the course of individual performances in the attempt to smooth out fortuitous variations. The individual performances are the final criteria by which any method of averaging should be tested. Our data show unmistakably that for individual performances the S-curve is typical. If a Vincent curve does not reveal certain of the features of these individual performances, there is something wrong with the Vincent method.

Procedure for Constructing Vincent Curves

Great care is needed in the construction of Vincent curves to avoid artifacts due to the criterion. Melton (**8**) has called attention to the end-spurt which is found as an artifact in the Vincent-Kjerstad method of constructing memorization curves, and the same thing can be shown to hold for other Vincent curves whenever, to quote Melton, "marked fluctuations in performance occur during progress to the criterion." This is usually the case. There is at least one such end-spurt in Hunter's curves (**6**, p. 126).

In order to compare our results with Hunter's, we used as he did a criterion based on consecutive conditioned responses. In each of our reinforcement trials it was possible to determine whether or not a conditioned response occurred. While responses differed in amplitude, for the present purpose any

measurable conditioned response (1 mm or over on our records) is counted equal to any other conditioned response in determining scores. Each trial therefore may or may not have a conditioned response. The criterion is reached when each of a series of consecutive trials yields a conditioned response. We have used criteria of 3, 5, and 10 consecutive responses.

The principle adopted by us in selecting the particular method to be used in constructing our Vincent curves was that no trial should be included in the curves which was not free either to have or not to have a conditioned response. This avoids the major artifacts of the Vincent method. Our principle obviously eliminated the criterial trials because, by definition, they all yielded conditioned responses. It also eliminated the trial just prior to the criterion, because this could not have a conditioned response, or the criterion would have been reached earlier. The remaining trials were uninfluenced by the criterion, except for the limitation which it imposed on maximum success. That is, in the period of trials prior to the criterion there can be no series of consecutive responses longer than the number of criterial trials minus one. This limitation applies to all of the trials prior to the criterion, and does not therefore influence the form of the curve to any considerable extent.[1]

The remaining trials, after eliminating the criterial trials and the trial just prior to the criterion, constituted the total trials entering into the calculation of our individual Vincent curves. These trials were divided into fifths and the number of conditioned responses per fifth determined. The frequencies thus obtained were then converted to percent, so that the final individual Vincent curve appears as percent of total conditioned responses to the criterion occurring in

[1] The distortion of probabilities introduced by the selection of an arbitrary criterion is very complicated, and cannot be treated more fully here. It must be stated, however, that a limited maximum, although it theoretically operates throughout the whole series of trials, has little influence on scores until that portion of the performance curve in which the maximum is being approached. Therefore, different possible maxima, determined by the choice of criteria, do distort slightly the form of the curve obtained by averaging the results of subjects requiring different numbers of trials to mastery.

each fifth of practice trials. The total of the five fifths for each subject is 100 percent. The subjects are weighted equally in this manner. It is evident that other methods of weighting might have been chosen, making allowance for the greater reliability of percentages based on larger numbers of trials. It suited our purposes better, however, to have subjects equally weighted rather than to have responses equally weighted. In order not to include individual curves very obviously unreliable, subjects were eliminated if the individual Vincent curve by our method was based on fewer than 10 trials. Stated otherwise, subjects were included only if one-fifth of their trials prior to the criterion included at least two trials. Average Vincent curves were secured by grouping the individual curves.

The Effect on the Vincent Curve of More Lenient and More Severe Criteria

Hunter found the severity of the criterion to affect the form of the Vincent curve of conditioning. His curves contain artifacts, however, because of the inclusion of the criterial trials in determining the tenths of the practice period. Criterial trials reduce variability and artificially increase scores within the final tenths of practice. How early in the curve the artificial effects of the criterion are introduced depends both on the number of trials included in the criterion and on the trials to mastery. When the criterial trials furnish a larger proportion of practice time, the Vincent curve will show an earlier rise than when they constitute a lesser proportion of practice time. Without a re-examination of Hunter's original raw data there is no way of determining what part of his finding is artifact, and what part is significant with respect to performances of rats under the conditions of his experiments. In our data, artifacts would be prominent if Hunter's method were used, because several of our subjects reached the more severe criterion at the same time that they reached the less severe one. Including the criterial trials in determining their Vincent curves would have shown an earlier rise with the more severe criterion, which seems illogical since

identical performances precede both criteria. There is another reason for an earlier rise in the Vincent curve with a more stringent criterion, however, because of the common finding that performance curves become negatively accelerated as practice continues. The phase of negative acceleration should result in a higher proportion of responses distributed through the later portions of the Vincent curve with more severe criteria, yielding Hunter's curves. In order to determine to what extent the empirical findings bear out these expectations, we have computed our data with three criteria, eliminating the artifacts due to criterial trials as indicated above. Only those subjects were included who attained the most severe criterion (10 consecutive responses) within 100 reinforcement trials. This eliminated 20 of our 63 subjects.[2] Those were also eliminated who attained the least severe criterion (3 consecutive responses) so early that less than 10 trials would be included in their Vincent curve. This eliminated 13 more subjects, leaving a total of 30. Three more subjects were dropped because they gave no conditioned responses whatever before reaching the criterion, and by our method their curves are indeterminate.[3] There remain 27 subjects providing the data for the curves showing the influence of the criterion. The same subjects enter each curve; the identical series of trials of each subject is plotted in each curve, but the series is cut off at different points. The curves showing the effects of choosing different criteria are presented in Fig. 1.

In the first place, all of the curves are positively accelerated. This agrees with the initial performances of our raw individual curves, and with the Vincent curve presented by Hull (5). The stage of negative acceleration is not reached early enough to show as such in the curves. It would appear if more trial units, equal in length to the fifths here plotted,

[2] Only the 51 of these 63 subjects who served a third day were included in the curves earlier reported (4). All of the subjects were treated with respect to individual differences (1).

[3] The performances of these three subjects are of considerable interest, but they can provide no curve of percent of total responses per fifth of trials since there are no responses to be distributed over the fifths. Arbitrarily, a horizontal line might have been entered as their contribution, but this would simply have flattened the curves without adding much information.

were added, including criterial trials and beyond. It is not possible to plot these added trials without elaborate corrections for the statistical artifacts involved, but the nature of the criterion demands logically that there be negative acceleration as more consecutive responses are given. It is not possible to have more than one conditioned response per trial, hence a maximum per unit number of trials must be reached as more consecutive responses appear. The approach to such a maximum forces negative acceleration. If Hunter's curves were continued beyond the criterion, they too would show negative acceleration.

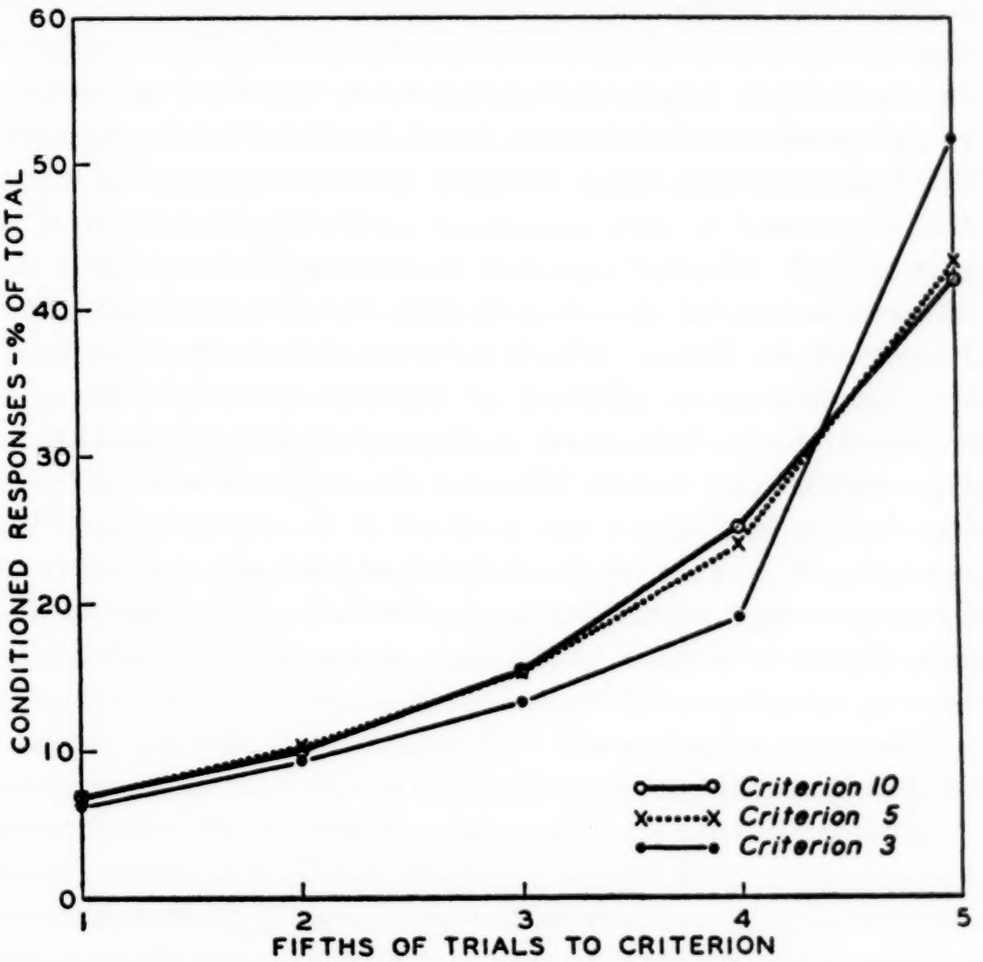

FIG. 1. Effect of criterion on form of Vincent curve. Data from the same 27 subjects enter each of the curves, but different proportions of the data are used with the more lenient and the more severe criteria.

The above interpretation implies that the more severe the criterion, the earlier in the Vincent curve should the

influence of negative acceleration appear. This influence may show as such, or only as a lessened positive acceleration. The greater positive acceleration of the curve based on a criterion of 3 responses is predictable on this basis. A greater difference might have been anticipated between a criterion of 5 and one of 10 consecutive responses, but our curves are alike within the limits of experimental error. The reason for the similarity is largely accounted for by 19 of the 27 subjects who yield identical curves for 5 and 10 consecutive responses. The first time that these subjects gave 5 responses in a row they continued to give responses until they had reached at least 10. By Hunter's method these would have yielded two different curves; by our method, since the criterion is excluded, the curves are alike. The 8 subjects for whom more trials were required to a criterion of 10 than to a criterion of 5 responses do in fact show a slightly higher proportion of responses in the fourth fifth for the more severe criterion than for the less severe one, a result to be expected from the increasing flattening of the individual performance curve as the more stringent criterion is approached. Thus our results, with Hunter's artifact eliminated, agree with his results in showing an influence of the criterion on the form of the curve.

Does our experimental agreement with Hunter support his doubt regarding the applicability of the Kjerstad-Robinson Law to conditioning? There is a fallacy in his assumption that the course of performance in reaching a more severe criterion should compare with the course of performance in reaching a less severe criterion just as the course of performance in memorizing a long list compares with the course in memorizing a short list. There is an obvious difference between the two comparisons. The less severe criterion is reached on the way to the more severe criterion. It is not true that a short portion of a long list is memorized independently while attaining eventual success on the long list. The common negative acceleration of the practice curve would tell us in advance that a Vincent curve based on a more severe criterion, if it is at all representative of individual performances, must differ from a curve based on less severe criteria.

No invalidation of the Kjerstad-Robinson principle is involved.

The Effect of Different Rates of Conditioning on the Vincent Curve

The Kjerstad-Robinson formulation applies to difficulty of material (expressed as length of list) rather than to degree of mastery (severity of criterion). It is not possible to find within simple conditioning a situation strictly comparable to the memorization of lists of different length. One comparison is, however, instructive. It is possible to separate those subjects who reach a given criterion of mastery rapidly from those who reach it slowly, and thus we may secure performance curves for different rates of conditioning. While these two groups have not performed tasks differing in difficulty,[4] a comparison of their performance curves allows the formulation of a theorem which appears to be similar to the Kjerstad-Robinson Law.

We chose the criterion of 5 consecutive responses because it is sufficiently severe to be reached late enough to provide reliable curves, yet early enough to include more subjects than the criterion of 10 responses. Of the 63 subjects, 7 failed to reach the criterion within the 100 trials, 7 reached it too early to allow enough trials for a reliable curve, and two yielded no conditioned responses prior to the criterion. There remained 47 subjects meeting our requirements. Before calculating the individual Vincent curves, the subjects were distributed according to the number of trials required to the criterion. The subjects fell naturally into two groups.[5] The groups consisted of 22 slow conditioners, requiring a mean of 59 trials prior to the criterion (range of trials 46–91), and of 25 rapid conditioners, requiring a mean of 20 trials to the

[4] Unless it be assumed that for the subjects requiring longer to reach the criterion the task is necessarily more difficult than for those who reach it earlier.

[5] The criterion of 5 consecutive conditioned responses is not to be confused with our criterion score based on the 5th conditioned response, used in our study of individual differences (1). In that study we wished an early criterion, to show the beginning of conditioning. In this study we wish a late criterion, to show the course of performance as conditioning becomes better established.

TABLE 1

DATA FOR VINCENT CURVES FROM GROUPS OF SUBJECTS REQUIRING DIFFERENT NUMBERS OF TRIALS TO REACH THE SAME CRITERION

		Rapid Conditioners 25 Subjects	Slow Conditioners 22 Subjects
		Mean and σ_m	Mean and σ_m
Trials entering into computation of values for Vincent curves		20 ± 1	59 ± 3
Percent of conditioned responses occurring in each one-fifth of trials prior to criterion of 5 consecutive conditioned responses	First fifth	7 ± 4*	4 ± 1
	Second fifth	12 ± 2	12 ± 2
	Third fifth	16 ± 3	15 ± 3
	Fourth fifth	24 ± 4	26 ± 3
	Fifth fifth	41 ± 6	43 ± 4

*A single aberrant case distorts these values. If eliminated, the mean and standard error become 3 ± 1. The other values also are altered, so that for 24 subjects successive fifths would read 3, 13, 16, 25, 43.

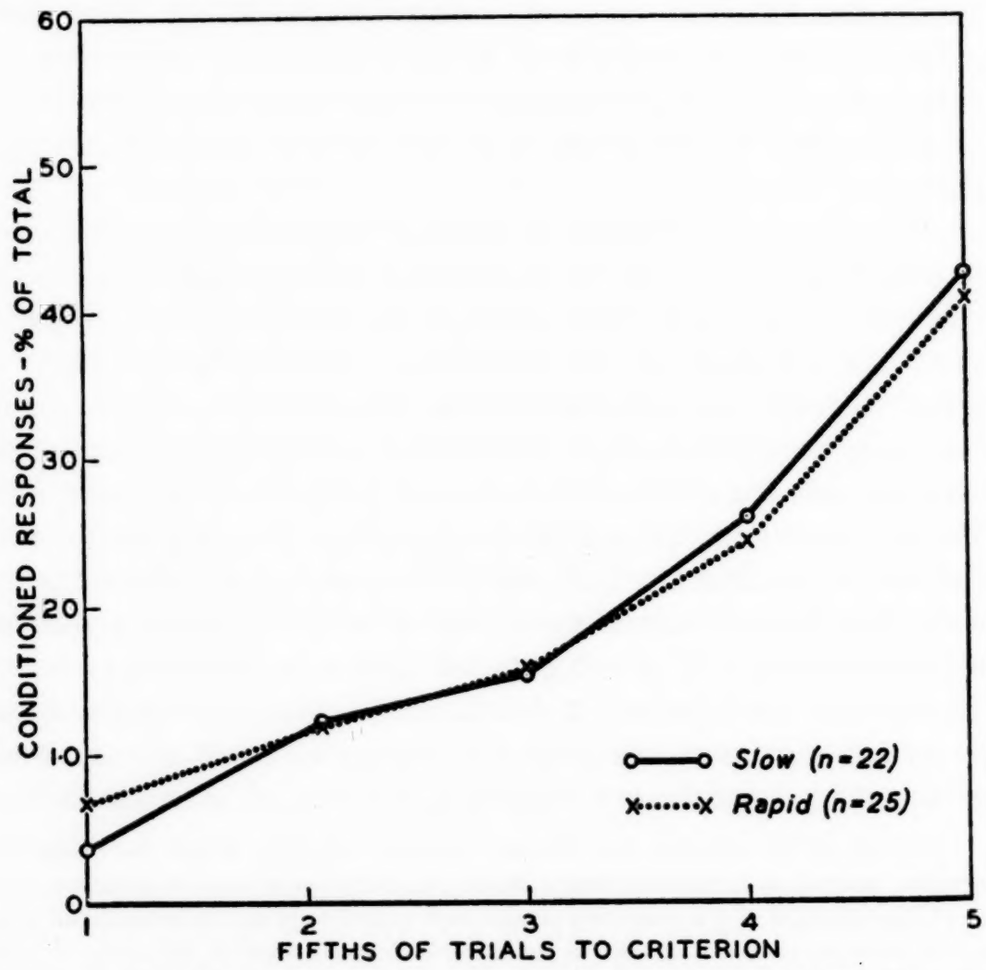

FIG. 2. Effect of different rates of conditioning on the form of the Vincent curve. The 22 subjects who conditioned more slowly required an average of 59 trials to reach the criterion of 5 consecutive conditioned responses. The 25 subjects who conditioned more rapidly reached the same criterion in an average of 20 trials.

criterion (range, 10–33). The results are presented in Table 1 and plotted in Fig. 2.

Although the slow group required three times as many trials before the criterion as the rapid group, the curves for the two groups are as similar as the unreliability of the measurements allows. A tentative theorem may be stated: "The form of the Vincent curve of conditioning is independent of the trials required to reach a given criterion of mastery." This relationship is far from established by our limited experiment, but it is perhaps deserving of further investigation.

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References

1. Campbell, A. A., and Hilgard, E. R., Individual differences in ease of conditioning, *J. Exper. Psychol.*, 1936, **19**, 561–571.
2. Hilgard, E. R., Conditioned eyelid reactions to a light stimulus based on the reflex wink to sound, *Psychol. Monog.*, 1931, **41**, No. 184, pp. 50.
3. Hilgard, E. R., The relationship between the conditioned response and conventional learning experiments, *Psychol. Bull.*, 1937, **34**, 61–102.
4. Hilgard, E. R., and Campbell, A. A., The course of acquisition and retention of conditioned eyelid responses in man, *J. Exper. Psychol.*, 1936, **19**, 227–247.
5. Hull, C. L., Learning: II. The factor of the conditioned reflex. In Murchison, C. (Ed.), *A handbook of general experimental psychology*, Worcester, Mass.: Clark Univ., 1934, 382–455.
6. Hunter, W. S., Learning curves for conditioning and maze learning, *J. Exper. Psychol.*, 1936, **19**, 121–128.
7. McGeoch, J. A., Curves of memorization after different amounts of practice, *Amer. J. Psychol.*, 1933, **45**, 678–690.
8. Melton, A. W., The end-spurt in memorization curves as an artifact of the averaging of individual curves, *Psychol. Monog.*, 1936, **47**, No. 212, 119–134.

STUDIES IN RETROACTIVE INHIBITION: X. THE INFLUENCE OF SIMILARITY OF MEANING BETWEEN LISTS OF PAIRED ASSOCIATES

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Introduction

Psychological activities go on in sequences within which each preceding term is stimulus to or instigator of the following response or instigated term. The description of the terms may vary with one's theoretical system, but the fact of sequence remains. The interrelations of the terms in successive groups of sequent terms is, moreover, constantly being altered and later performance is a function of these alterations. In some of these alterations interference must take place and the amount of the interference is presumably a function of the relations among the terms. We have measured in this experiment the inhibitory effects of certain relations between the terms in two successive sets of individual stimulus-response sequences.

We have employed lists of paired associates because in them each pair is distinct from the others and is treated as separate. With serial lists the learning is of this sequent paired associate form, but in most cases each succeeding response term, save the last, is a stimulus to the next response, and each stimulus term, save the first, is also a response to the preceding stimulus. In the learning of paired associates, however, each stimulus is a stimulus only and each response a response only, save, perhaps, for some influence of serial association of the pairs, which should, however, have no differential effect upon the results. Using lists of paired adjectives as the original learning material, we have interpolated lists of other paired adjectives which were unrelated to those in the original list, and of which either the first or

second members or both were synonyms of the corresponding adjectives in the original list.

Certain results of experiments on the conditions of transfer and related problems imply that retroactive inhibition should vary with the terms which are made synonymous. We shall discuss these results later. Quite aside from them, it is necessary, in view of the sequential character of psychological activities, to analyze the interrelations of sequent sets of terms, if we are to construct a systematic body of knowledge about the conditions of retention.

Procedure

The learning materials were pairs of adjectives in lists of 10 each. They were read to the subject at the rate of one pair every 3 seconds by an experimenter who had practiced reading them until the rate and the other features of the method had become habitual. In order to facilitate perception of each pair as a unit, the experimenter's voice was lowered slightly at the end of each second member and there was a slightly greater interval between pairs than between the members of a pair. The 3 seconds includes, however, the total time spent per pair, so that the total time per repetition is 30 seconds. An interval of about 5 seconds elapsed between successive presentations. Experimenter and subject were separated from each other by an opaque cloth screen. A mirror was arranged to give the experimenter full view of the subject without the latter's knowledge, and to permit a check on the possibility that the subject might write down the pairs as read to him and then read from his record at the recall.

In each condition the list was presented 5 times with the pairs in the same serial order at each presentation. Immediately after the fifth presentation, the first members were given alone in a random order and the subject was instructed to recall the right associate. Five seconds were allowed for the recall of each one; if the subject had not recalled at the end of that time, the next stimulus member was presented. Timing was controlled by a large seconds-timer in front of the experimenter. In using this method of presentation it is impossible to maintain rigid accuracy of timing, but practice and care on the part of the experimenter can reduce deviations to a minimum. There is no reason to believe that this remaining minimum has significantly influenced the results.

The experiment comprises one rest and 4 work conditions. In the rest condition the subject was given 5 presentations and a test, followed by 10 minutes of reading jokes, under instruction to mark the 3 best on each page, and then by relearning to 3 perfect recalls in succession. The procedure in relearning duplicated that in learning except for the fact that a test (presentation of first members) was given before the list was presented again and also after each presentation of the pairs until the 3 perfect tests or recalls had been reached. Tests and presentations thus alternated during relearning, with a test coming first.

In the work conditions the 5 presentations for learning, and the test, were followed 30 seconds later by 5 presentations and a test of a second or interpolated list. The remainder of the ten-minute interval (slightly more than 5½ minutes), corresponding to the interval under the rest condition, was filled by the reading of jokes, after which

the original list was relearned to 3 perfect recalls in succession and the interpolated list was given 2 tests and one presentation. The latter were introduced in order to prevent a suspicion on the part of the subject, as the experiment progressed, that the interpolated lists were less important and deserved less effort than the original lists.

The interpolated lists under the 4 work conditions bore certain specified relations to the original lists. In Work 1 neither member of the interpolated list was related in any apparent way to either member of the original list; in Work 2, the first members of the pairs in the interpolated list were synonyms of the corresponding first members of the pairs in the original list; in Work 3, the second members of the interpolated pairs were synonyms of the corresponding second members of the pairs in the original list; and in Work 4 both members of the interpolated pairs were synonyms of the corresponding pairs in the original list. The relations are summarized in Table 1.

TABLE 1

SUMMARY OF THE WORK CONDITIONS

Work Condition	Character of the Relation Between Original and Interpolated Lists
1	No relation
2	First members synonymous
3	Second members synonymous
4	Both members synonymous

Forty subjects, college students with no prior experience upon this experimental procedure, went through the rest condition and the 4 work conditions in a counterbalanced practice order. Eight others went through only the rest condition and the first 3 work conditions. One set of lists was employed with half of the subjects and a different set with the other half, in order to prevent the results from being functions of specific lists. There is no evidence to indicate a difference between the results from the two sets of lists.

The amounts learned during the 5 presentations of both original and interpolated lists have been measured in terms of the numbers recalled at the immediately following test. Retention has been measured in terms of the 4 following scores: (1) Recall 1, the number of right associates at the first test after the interval and before the list had been presented again; (2) Recall 2, the number of right associates at the second test, after the first relearning presentation of the pairs; (3) Relearning 1, the number of presentation trials required to reach one perfect test after the interval; and (4) Relearning 2, the number of presentation trials required to reach 3 perfect tests in succession. The relearning scores do not include the criterial trials, but only the trials required to reach the criterion.

RESULTS

The data of Table 2 show the extent to which the constant frequency of 5 presentations has yielded comparable measures of learning. The rest condition and the first 3 work conditions differ only slightly and unreliably from each other in amount of original learning. The same is true for interpolated

learning under the first 3 work conditions. Both original and interpolated learning under Work 4 are less than under any other condition, though unreliably so. These differences between Work 4 and the other conditions must, however, be remembered in interpreting the data.

TABLE 2
NUMBER OF ITEMS LEARNED UNDER EACH CONDITION, AS MEASURED BY THE IMMEDIATELY FOLLOWING TEST

List	Condition				
	Rest	Work 1	Work 2	Work 3	Work 4
Original					
M	7.60	7.98	7.56	7.48	6.43
σM	.28	.31	.31	.33	.42
Interpolated					
M		8.02	7.73	7.87	7.02
σM		.27	.31	.33	.41

The basic data upon retention (means and sigmas of the means) are presented in Table 3, and the major results can

TABLE 3
MEAN RECALL AND RELEARNING SCORES

Condition	Score							
	Recall 1		Recall 2		Relearning 1		Relearning 2	
	M	σM	M	σM	M	σM	M	σM
Rest	6.56	.32	8.58	.26	1.73	.23	1.92	.27
Work 1	5.38	.38	8.38	.29	1.92	.20	2.00	.22
Work 2	4.21	.43	7.08	.41	2.75	.29	2.98	.34
Work 3	5.00	.45	7.63	.34	1.96	.34	2.17	.25
Work 4	3.93	.48	6.93	.43	2.68	.29	2.73	.31

be seen by making direct comparisons of the means. Comparisons are aided, however, by a statement of the relative amounts of inhibition. Percentages of inhibition have been computed by the formula *Rest Score minus Work Score/Rest Score*, using the mean recall and relearning scores of Table 3. These percentages appear in Table 4.

The learning of each interpolated list has produced some retroactive inhibition by each method of measuring retention

and, what is more important for the present problem, the 4 work conditions differ in the amounts of inhibition produced. Inhibition is least, by each of the measures, when the members

TABLE 4

PERCENTAGES OF INHIBITION COMPUTED FROM MEAN RECALL AND RELEARNING SCORES

Condition	Score			
	Recall 1	Recall 2	Relearning 1	Relearning 2
Work 1 (No relation)	17.9	02.3	10.9	04.2
Work 2 (1st member syn.)	35.8	17.5	58.9	55.2
Work 3 (2nd member syn.)	23.8	11.0	13.3	13.0
Work 4 (Both members syn.)	40.1	19.2	54.9	42.2

of the interpolated list bear no specified relations to the members of the original list (Work 1). It is slightly higher, although not much, when the second members of the interpolated list are synonyms of the second members of the original list (Work 3). It is still higher when either the first members of the two lists (Work 2), or both members (Work 4), are synonymous. In terms of the two recall scores, inhibition is higher under Work 4 than under Work 2, but in terms of the two relearning scores this relation is reversed. No difference between any two means under the work conditions is as much as 3 times the sigma of the difference. The 4 measures of retention yield consistent results upon the comparisons of Work 1 and Work 3 with each other and with the other conditions, but they give inconsistent results on comparisons of Work 2 and Work 4.

Remembering the lack of complete statistical reliability, but remembering at the same time that the probabilities in favor of the validity of the direction of the differences between Work 1, Work 3, and the two other work conditions are high, one may summarize the results further. A study of fractionations of the data also supports the summary. (*A*) Interpolated learning of a second list of paired adjectives, whatever their relation to the adjectives in the original list, produces at least some decrement in the retention of the latter. (*B*) When, however, the members of the interpolated

list are in no specified way related to the members of the original list, save for the fact that both lists contain adjectives, the decrement is very small. (*C*) When the second members of each interpolated pair are synonyms of the second members of the original pair in the same position, the decrement is only slightly larger. In view of the unreliability of the differences, the safest conclusion is that little if any difference exists between the inhibitory effects of entirely unrelated lists and lists in which the second members are synonyms of the original second members.

(*D*) The amount and consistency of the increase in the decrement, when the first members of the original and interpolated pairs are synonymous, leave little doubt that this condition yields more inhibition than does synonymity of the second members and than does an unrelated list. The stimulus member of the pairs is, thus, the dominant one under these experimental conditions. (*E*) This dominance of the stimulus term is further demonstrated by the fact that addition of synonymity in the second members, so that both members of the interpolated pairs are synonyms of the corresponding members of the original list, does not significantly alter the amount of the decrement. Amount of inhibition is approximately the same, whether both members, or first members only, are synonymous. The relations between the second members of the original and interpolated pairs, whether the first members are synonymous or not, are relatively inconsequential. (*F*) It is interesting, also, that although inhibition in terms of Recall 2 is relatively small throughout, it is large in terms of both relearning scores under Work 2 and Work 4.

Discussion

Earlier experiments with serial lists, learned by the anticipation method, have found synonymity between the members of the original and interpolated lists to be a highly favorable condition for the production of retroactive inhibition (**3, 4**). The present experiment verifies this result and extends it to paired associates, specifying, however, that the

major effect of the synonymity is localized in the stimulus members of the original and interpolated pairs.

The discovered dominance of the stimulus term in this experimental setting is in harmony with the implication of other results upon the learning of paired associates. Thorndike (**6**) has found evidence for the greater influence of impressiveness in the first member than of impressiveness in the second member. Winzen (**7**) and Cason (**2**) report that association is favored by primacy within a pair of the more familiar of the two terms. The greater inhibitory potency of synonymity of stimulus members might be guessed from these results, although prediction from them to the results upon retroactive inhibition cannot be made directly.

The present results may also be interpreted as continuous with those of Wylie (**8**) and Bruce (**1**) on the conditions of transfer in learning. They found that learning to make a new response to an old stimulus is an optimal condition of negative transfer, and our results upon retention are similar to this. When the first or stimulus members are synonymous, the first members of the interpolated list are 'old' stimuli to the extent that they have for the subject a core of meaning in common with the first members of the original list, and this condition yields a maximal decrement in retention. When the second members are synonymous, on the other hand, they are 'old' to the same extent and, on the basis of Bruce's results, positive transfer should be favored. This expectation is borne out by the failure of this condition to exhibit a significantly larger amount of inhibition than was shown by the interpolation of unrelated lists. We should not expect actual positive transfer in retention because of the operation of other common factors which act to produce a decrement and which could readily mask small amounts of positive transfer. When both members are synonymous, the synonymous first terms, which are dominant in the production of negative transfer, retain their inhibitory potency.

The Bruce experiment, which is the one most immediately relevant, was upon transfer in learning and predictions from it apply directly only to learning. Reference to Table 2

will show that such predictions are not fulfilled in the learning data of this experiment. It is true that the means for the interpolated lists under Work Conditions 2 and 4, are somewhat less than those under Work Conditions 1 and 3, as would be expected from the Bruce results. The differences are small and unreliable and, in view of the smaller mean for original learning under Work 4, the smaller mean for interpolated learning cannot be made to bear any great interpretive weight. The means for the interpolated lists are, moreover, larger than those for the original lists, and fail, therefore, to exhibit any negative transfer in learning.

The failure of the learning data to conform to expectation does not necessarily mean that the retention data cannot be interpreted as continuous with the Bruce results. In his experiment different groups learned under each condition; in this one, the same subjects have gone through all conditions in a counterbalanced order. The interrelations of lists which are introduced by counterbalancing may well have obscured the negative transfer in learning, while failing to obscure them in retention. Furthermore, an experiment by McGeoch, McKinney and Peters (**5**) has shown that reproductive inhibition may appear without corresponding associative inhibition, which means that a decrement may appear in retention, as a function of a common stimulus member, without the appearance of a corresponding decrement in learning. It seems reasonable, therefore, to regard the present results as an extension from learning to retention of the conclusion that negative transfer is favored by learning to make a new response to an old stimulus.

The present results are consonant with the hypothesis set forth in earlier papers of this series that retroactive inhibition conforms to the paradigm of reproductive inhibition, according to which the decrement in retention is a function of terms common to both original and interpolated lists. The data show directly that synonymity of the stimulus terms is a significant variable in the production of a decrement; the common factor here is the meaningful connections of the two initial members of corresponding pairs. The interpretation

of retroactive inhibition as a form of reproductive inhibition is supported, also, to the extent that the results of this experiment can be regarded as continuous with those on the conditions of transfer in learning.

Summary

The interpolated lists of paired associates have represented the following relations to the original lists: no specified relation, first members synonymous, second members synonymous, both members synonymous. The influence of the various interpolations and the implications of the obtained results are as follows.

1. Each interpolation produces some retroactive inhibition, but the amounts produced by an unrelated list and by one the second members of which are synonyms of the second members in the original list are relatively small. The unrelated lists and the lists with second members synonymous do not differ significantly from each other in the amount of the decrement produced.

2. Interpolated lists the first members of which are synonyms of the first members in the original list yield larger decrements in retention. These decrements are not significantly altered when the second members are also synonymous.

3. The first members of associated pairs are, under the conditions of this experiment, the dominant terms in the production of retroactive inhibition.

4. These results are interpreted as supporting the hypothesis that the phenomena of retroactive inhibition may be subsumed under the paradigm of reproductive inhibition.

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References

1. Bruce, R. W., Conditions of transfer of training, *J. Exper. Psychol.*, 1933, **16**, 343–361.
2. Cason, H., Associations between the familiar and the unfamiliar, *J. Exper. Psychol.*, 1933, **16**, 295–305.
3. McGeoch, J. A. and McDonald, W. T., Meaningful relations and retroactive inhibition, *Amer. J. Psychol.*, 1931, **43**, 579–588.

4. McGeoch, J. A. and McGeoch, G. O., Studies in retroactive inhibition: VI. The influence of the relative serial positions of interpolated synonyms, *J. Exper. Psychol.*, 1936, **19**, 1–23.
5. McGeoch, J. A. McKinney, F. and Peters, H. N., Studies in retroactive inhibition: IX. Retroactive inhibition, reproductive inhibition and reminiscence, *J. Exper. Psychol.*, 1937, **20**, 131–143.
6. Thorndike, E. L., *The fundamentals of learning*. New York: Teachers Coll., 1932, pp. 140 ff.
7. Winzen, K., Die Abhängigkeit der paarweisen Assoziation von der Stellung des besser haftenden Gliedes, *Zsch. f. Psychol.*, 1921, **86**, 236–252.
8. Wylie, H. H., An experimental study of transfer of response in the white rat, *Behav. Monog.*, 1919, **3**, No. 16, pp. 66.

THE INFLUENCE OF ELECTRIC SHOCKS FOR ERRORS IN RATIONAL LEARNING

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Several experimental studies on both human and animal subjects show that electric shocks for errors have, under a rather wide variety of conditions, a highly beneficial influence upon the efficiency of learning. The conditions under which learning has been measured, when electric shocks have been used, have not been sufficiently uniform, however, to permit of statements concerning the extent to which the influence of shocks, whether helpful or detrimental, in learning, is a function of particular aspects of the learning situation, as, *e.g.*, the material being learned. It is a question what influence electric shocks would have upon learning efficiency when the problem being mastered is not a motor problem such as a maze, or one involving the mastery of a fixed series, but one which permits of a certain amount of rational selection of paired associates placed in a carefully defined and circumscribed framework, such as Peterson's Rational Learning Problem (**8**). The experiment reported here was conducted to answer this question, and the general conditions of administering electric shocks for errors, *e.g.*, the intensity used, were kept as nearly as possible the same as those employed in earlier maze studies (**1**, **2**, **3**) in which shocks increased the efficiency of learning from 30 to 60 percent according to the different criteria.

In studying the influence of electric shocks for errors upon the learning of the Rational Learning Problem the oral method of presenting the problem, employed by Peterson, was modified to facilitate the condition of administering shocks.

A specially constructed piece of apparatus was employed which performed the following functions: 1, presented the letters visually, and one at a time; 2, required a definite hand movement of the subject; 3, gave the subject an electric shock immediately upon the occurrence of an incorrect guess; 4, presented the next letter in the trial when the subject responded correctly to the one before him; and, 5, indicated to the experimenter, who sat on the opposite side of the apparatus from the subject, the numbers guessed in response to the letter exposed.

The apparatus[1] consisted essentially of two rectangular boxes, one 14″ × 18″ × 6″ of bakelite surmounted by a second wooden box 9″ × 10″ × 6″. The letters were exposed singly through an aperture in the latter box. The subject guessed numbers for the letter exposed by (1) turning the dial on the face of the larger box until the arm attached to it pointed to the number he wished to guess, and (2) pushing in the on dial. On the subject's side of the larger box were metal numbers from 1 to 10 arranged in a semicircle with a radius of seven inches. Placed radially from each of these numbers were three brass electrical contact points. When the subject, in guessing a number, pressed in on the dial the narrow strips of metal at the end of the metal arm of the dial made contact with three brass points under the number being guessed. Contact with one brass point closed a circuit and lighted a small bulb on the experimenter's side of the apparatus thus indicating which number had been guessed. Contact with the second brass point, when the correct number was guessed for the letter exposed, caused the disc in the smaller box to rotate to its next position and expose the letter next in the series. Contact of the metal arm with the third brass point, for all the possible numbers except the correct number for the letter being shown, completed a circuit and shocked the subject. The experimenter controlled these factors by means of a system of switches on his side of the apparatus. Each subject grasped the dial with the forefinger and thumb of the right hand, and held the left palm firmly pressed against a metal plate 5″ × 6″ at the left side of the apparatus. The shock was felt in the hand grasping the dial. An intensity of 27 volts A.C. was used for all individuals receiving electric shocks in this experiment, as in the maze studies referred to above.

The subjects for this experiment were 190 undergraduate students in Introductory Psychology classes. They were divided into four groups on the basis of the conditions under which learning took place. These conditions are shown in Table 1 and will be described more in detail below under the heading of the particular questions which they were designed to answer. Each group contained an equal number of men and women subjects. The criterion of mastery was two errorless trials in succession.

What is the influence of electric shocks for errors upon the learning of the Rational Learning Problem?

The efficiency of learning the ten-letter problem when electric shocks are administered for errors and when they are

[1] The apparatus described here was designed and constructed by Mr. Peter C. Gaskill.

not was determined under two different conditions of letter presentation: (*a*) with the letters presented in alphabetical

TABLE 1.
PROGRAM OF THE CONDITIONS OF LEARNING FOR EACH GROUP

Group	No. of Subjects	Method of Presentation	Order of Presenting Letters	Conditions of Learning
AV.....	20	Visual	Alphabetical	Normal
AVS.....	20	Visual	Alphabetical	Shocks for errors
RV.....	68	Visual	Random	Normal
RVS.....	82	Visual	Random	Shocks for errors

order each trial, and (*b*) with the letters occurring in random order.

During previous work with Peterson's Rational Learning Problem it was noted that occasionally a subject was apparently not learning the letters and numbers as pairs but was memorizing the numbers from 1 to 10 in a new order. It does not cease to be a rational learning problem because of this feature, but the presence of a certain amount of serial memorization in the problem is undesirable. As a means of discouraging even the occasional use of such procedure, a condition was employed in which the letters from A to J were paired with the same numbers but were presented in random order instead of alphabetical order each trial. A shuffled order of the letters for each trial was determined, as described previously (4), for twenty trials, and if a subject required more than this number to learn the problem, trial 21 began again with the order determined for the first trial, and so on.

(*a*) *The influence of electric shocks for errors when the letters of the problem are presented in alphabetical order each trial.*

The subjects in group AV learned the problem with the letters occurring in alphabetical order each trial and presented by the visual method. The subjects in group AVS mastered the problem under the same conditions with the additional factor that an electric shock was administered immediately upon the occurrence of an error or wrong guess. A comparison of these two groups will indicate the influence of electric shocks for errors upon the efficiency with which the ten-

letter Rational Learning Problem is mastered. The data are presented in Table 2.

TABLE 2

INFLUENCE OF ELECTRIC SHOCKS FOR ERRORS WHEN THE LETTERS OF THE PROBLEM ARE PRESENTED IN ALPHABETICAL ORDER EACH TRIAL

Group	Trials		Time		Errors							
					Total		Unclass.		Logical		Per.	
	Ave.	σ Ave.	Ave.	σ Ave.	Ave.	σ Ave.	Ave.	σ Ave.	Ave.	σ Ave.	Ave.	σ Ave.
AV	8.1	.51	665.8	68.9	117.5	12.8	81.9	8.12	27.3	4.06	7.7	1.24
AVS	7.0	.40	706.9	47.3	85.8	13.1	65.3	8.6	17.7	3.7	2.7	.9
Difference	1.1		−41.1		31.7		16.6		9.6		5.0	
Sigma of diff.	.64		83.57		18.31		11.82		5.49		1.53	
Critical ratio	1.72		.49		1.73		1.40		1.75		3.27	
Percent decrease of AVS under AV.	13.5		−6.1		26.9		20.2		35.1		64.9	

Under the condition of electric shocks for errors 13.5 percent fewer trials were taken in learning, 26.9 percent fewer total errors, 20.2 percent fewer unclassified errors, 35.1 percent fewer logical errors and 64.9 percent fewer perseverative errors, than occurred under normal non-shock condition. All the measures of learning are consistent in indicating a fairly pronounced increase in the efficiency of learning the problem under the condition of shocks for errors as compared with the normal condition, with the exception of the time score. There was an increase of 6.1 percent in the total amount of time taken to learn the problem as the result of shocks for errors. According to the critical ratios (Table 2) the chances are 96 in 100 that there is a true difference between the groups in terms of trials and three of the four error scores, while the chances are only 67 in 100 that the difference in terms of time, the only measure of learning which indicated a detrimental effect from shocks, is a true difference.

Under the shock condition a greater amount of time per trial was taken than occurred under the normal condition as may readily be inferred from the facts, stated above, that shock decreased the number of trials 13.5 percent at the same time that the total time taken was increased 6.1 percent. The

mean number of seconds per trial was 100.9 under the shock condition as compared with 82.1 under the normal AV condition. Along with this increase of 22 percent in the time per trial under the shock condition there was also an increase in the average time per response (whether correct or incorrect) from 4.0 to 5.2 seconds. These data would appear to indicate a more cautious attitude on the part of the subject, as the result of being punished for errors, which may be significantly related to the marked decrease that occurred in total as well as the different types of errors. The most pronounced effect was in terms of perseverative errors (repetition of a wrong guess while reacting to a single letter) which showed a decrease of 64.9 percent, and second in terms of logical errors (guessing a number which was correct for a letter presented earlier in that trial) which showed a decrease of 35.1 percent. It has been suggested that such errors as these should be regarded as more serious than those wrong guesses which could not have been eliminated on the basis of logical inference, and, perhaps should receive greater weight in the total score as suggested by Peterson, since the learning problem represents a study in rational learning. At any rate, it is in terms of these criteria of learning that the increase of efficiency of learning under the shock condition is greatest.

The question has been raised earlier and received some experimental attention in maze studies (**7**, **3**) as to whether the beneficial effect of electric shocks for errors is dependent upon the informative value or upon the punishment aspect of administering shocks for errors. No special study was made of the informative value, if any, of shocks for errors in the present experiment. In view of the fact that the learner had both a visual and an auditory cue (when a correct guess occurred the letter next in the trial appeared in the exposure apparatus and there was a slight, but clearly audible, click as the disc rotated one step) as to whether or not his guess was accurate, it seems likely that an additional cue indicating a guess to be in error would be of rather limited value. At least such was found to be the case, as regards errors, in a stylus maze study which was conducted under somewhat

similar conditions with respect to the occurrence of electric shocks for errors during learning.

(*b*) *The influence of shocks for errors when the letters are presented in random order each trial.*

The question here is, what is the influence of electric shocks for errors upon the learning of the ten-letter problem when the letters are presented in random order instead of alphabetical order each trial. A comparison of the records of group RV with those of RVS will indicate the effect of shocks under this condition. The data are shown in Table 3.

TABLE 3

EFFICIENCY OF LEARNING THE PROBLEM UNDER SHOCK AND NORMAL CONDITIONS WHEN THE LETTERS ARE PRESENTED IN RANDOM ORDER EACH TRIAL

Group	Trials		Time		Errors							
					Total		Unclass.		Logical		Per.	
	Ave.	σ Ave.	Ave.	σ Ave.	Ave.	σ Ave.	Ave.	σ Ave.	Ave.	σ Ave.	Ave.	σ Ave.
RV	14.96	1.08	1491.02	112.6	323.01	32.2	219.10	20.1	85.87	8.7	18.10	2.1
RVS	15.90	.79	1466.10	84.7	352.93	21.3	238.26	14.0	99.85	6.3	18.02	1.5
Difference	.94		−24.92		29.92		19.16		13.98		−0.08	
Sigma of diff.	1.33		141.2		38.6		25.69		10.74		2.58	
Critical ratio	.70		.18		.77		.74		1.3		.03	
Percent increase of RVS over RV	6.2		−1.6		9.2		8.7		16.2		−0.4	

When the letters of the problem are presented in chance order each trial, the influence of electric shocks for errors is slightly detrimental according to all measures of learning efficiency except the time and the perseverative error score. The subjects in the RVS group took 6.2 percent greater number of trials to learn, made 9.2, 8.7, and 16.2 percent more total, unclassified, and logical errors respectively than did the individuals of group RV. The difference scores, however, are all small and of doubtful significance statistically (Table 3).

The mean number of seconds per trial was 92.22 under the shock condition as compared with 99.59 under the normal RV condition. There was thus a slight decrease in the average time per trial as the result of shocks for errors, and the average time per response (whether correct or incorrect) like-

wise shows a slight decrease from 4.0 seconds to a value of 3.7 seconds. These effects from shocks for errors are slight indeed, but are rather consistently opposite in direction to those found under the condition of alphabetical order of presentation of the letters composing the problem.

According to these data, the influence of shocks for errors upon the mastery of the Rational Learning Problem varies significantly with the manner in which the problem is presented to the subjects. A beneficial effect upon learning from administering shocks for wrong guesses when the letters are presented in alphabetical order during learning becomes insignificant or slightly detrimental when the letters occur in random order each trial.

Immediately upon the completion of learning under the condition of alphabetical order of presentation, the letters of the problem were presented to the subjects in a changed order for the purpose of obtaining some information as to whether the subjects had followed the instructions to learn the letters and numbers as pairs. Some of the subjects made perfect scores on the first trial, some on the second, but four of the subjects under the normal and five under the shock condition made errors in regard to certain letters even on the second trial. It is quite likely that some errors would occur in adjusting to a new order of the letters when a fixed one had been employed during learning. A statement of the degree to which serial memorization entered during learning cannot be made, but the data do suggest that failure to follow the instructions to master the problem as a series of paired associates was probably the exception rather than the rule.

The difference in the effect of shocks for errors under the alphabetical as compared with the random order presentation may be a function of the relative difficulty of the task under the two conditions.

The difficulty of the Rational Learning Problem under different conditions of presentation.

Varying the order of presenting the letters each trial not only discourages occasional attempts at memorizing the numbers of the problem in a new order merely, rather than

pairing them with the letters as instructed, but changes other aspects of the problem as well, especially when the problem is presented by the visual method. The distinction between trials is less clear from the presentation of the letters themselves under the random order condition and hence the difficulty of avoiding those errors designated by Peterson as logical might reasonably be expected to be greater than is the case when the letters are called out in alphabetical order. Further, during the first trials when several wrong guesses were often made for each letter, some subjects indicated by their verbal responses that the letter exposed was almost completely disregarded in concentrating on the discovery of the correct number, with the result that the letter could not be recalled when its pair was found. As noted in describing the apparatus, immediately upon the occurrence of a correct guess the disc behind the aperture automatically rotated one step, thus exposing the letter next in the series. The letter which appeared was, of course, no index as to its predecessor under the random order condition.

The relative difficulty of the ten-letter problem, under normal non-shock conditions of learning, when the letters are presented in random instead of in alphabetical order during each trial is obtained by a comparison of the records of group RV with those of AV. The data, taken from Tables 2 and 3 above, are brought together in Table 4 for convenience in comparison.

Comparing the RV with the AV condition as a standard, it can be seen from Table 4 that presenting the letters in random instead of alphabetical order each trial increases the number of trials to learn 84.6 percent and more than doubles the difficulty of the problem according to all other criteria of efficiency. The difference scores are not only large and consistent in indicating greater difficulty of the problem under the RV condition but are more than four times the corresponding sigmas in all instances.

As noted in an earlier section, the shocks had a slight, but probably insignificant, detrimental effect upon learning under the more difficult condition involving random order presenta-

TABLE 4

EFFICIENCY OF LEARNING THE RATIONAL LEARNING PROBLEM BY THE VISUAL METHOD WHEN THE LETTERS ARE PRESENTED IN ALPHABETICAL AND IN RANDOM ORDER EACH TRIAL

Group	Trials		Time		Errors							
					Total		Unclass.		Logical		Per.	
	Ave.	σ Ave.	Ave.	σ Ave.	Ave.	σ Ave.	Ave.	σ Ave.	Ave.	σ Ave.	Ave.	σ Ave.
AV.....	8.1	.51	665.8	68.9	117.5	12.8	81.9	8.12	27.3	4.06	7.7	1.24
RV.....	14.96	1.08	1491.02	112.6	323.01	32.2	219.10	20.1	85.87	8.7	18.10	2.1
Difference (RV–AV)...	6.86		825.22		205.51		137.2		58.57		10.4	
Sigma of diff...	1.19		132.0		34.65		21.67		9.6		2.43	
Critical ratio ..	5.76		6.25		5.93		6.33		6.10		4.28	
Percent increase of RV over AV....	84.6		123.9		174.9		167.5		214.5		135.0	

tion of letters each trial, while the effect of shocks under the less difficult alphabetical order of presentation was distinctly beneficial in character. These data are consistent with a relationship between the effect of electric shocks for errors and the difficulty of the problem in rational learning that has been indicated in earlier studies of this question dealing with other kinds of learning material, namely, that the influence of a definite intensity of electric shocks for errors upon learning is partly a function of the difficulty of the problem and that perhaps the optimal intensity for difficult problems is less than is the case with simpler problems.

SUMMARY AND DISCUSSION

The question of the influence of electric shocks for errors in rational learning was investigated by using Peterson's ten-letter Rational Learning Problem and comparing the efficiency shown under normal non-shock conditions in the mastery of the task with that shown when electric shocks were administered for errors. In all, 190 undergraduate students were used as subjects, 88 learning the problem under normal conditions and 102 under the conditions of shocks for errors. In administering electric shocks for errors the conditions used

were made as nearly as possible the same as those employed in earlier studies in maze learning, *i.e.*, 27 volts, A.C. and kept at this value for all subjects. In the earlier studies the effect of the shocks was decidedly beneficial, increasing the efficiency of learning from 30 to 60 percent according to the various criteria of learning. Since electric shocks represent the variable under study, an apparatus was employed which required a definite hand movement on the part of the subject and administered a shock automatically upon the occurrence of a wrong guess, if the subject were learning under the shock condition. The letters of the problem were presented visually through an aperture in the apparatus and the subject responsed by pressing in on a dial, grasped between the thumb and the index finger of the right hand, after he had pointed it to the number he wished to guess. The shock was felt in the hand grasping the dial. When the correct number was guessed, the letter next in the trial automatically appeared in the aperture. Efficiency of learning was measured in terms of trials, time, and error scores taken to reach a criterion of two consecutive errorless trials.

The normal and the shock groups mentioned above were further subdivided into two groups each to determine the influence of shocks for errors under two conditions of letter presentation: (*a*) with the ten letters of the problem presented in alphabetical order each trial, as used by Peterson; and (*b*) with the ten letters presented each trial in a random order.

1. When the ten letters of the problem are presented in alphabetical order each trial, the efficiency of learning is considerably increased, according to trials and the various error scores, as the result of administering shocks for errors. Under the shock condition of learning, 13.5 percent fewer trials were taken to master the problem and 20.2 percent fewer wrong guesses (unclassified errors) were made than occurred under the standard condition. The most pronounced increase in the efficiency of learning as the result of shocks was in terms of the logical and the perseverative errors, the particular measures which perhaps indicate better than any of the other measures the extent to which the subject makes

use of the logical inferences offered by the problem. The decrease was 35.1 percent in the number of logical errors and 64.9 percent in the number of perseverative errors.

There was an increase of 6 percent, of doubtful reliability statistically, in the total amount of time taken in learning under the shock condition, and an increase of 22 percent in the time per trial. These data, combined with the marked decrease in perseverative and logical errors under the shock condition, suggest a much more cautious attitude on the part of the subject during the process of learning as the result of shocks for errors.

2. When the letters of the problem are presented in random order each trial the influence upon learning of shocks for errors is detrimental according to four of the six measures of efficiency. The difference scores, however, are small and of doubtful reliability statistically.

3. The difficulty of the ten-letter problem, under normal non-shock conditions of learning, is greatly increased as the result of presenting the letters in a random instead of in alphabetical order each trial. The increase was 84.6 percent in terms of trials, while the time and error scores were more than doubled. It is suggested that the differential effect of electric shocks for errors upon the mastery of the rational learning problem under the two conditions of letter-presentation is a function of the difficulty of the task.

4. It would appear that in rational learning, as in tasks usually regarded as more nearly motor in character such as a maze problem, electric shocks for errors may, under favorable conditions as regards such factors as intensity, manner of administering shock, etc., increase the efficiency of learning as much as from 30 to 60 percent depending upon the particular criteria in terms of which efficiency is measured. Obviously the influence of shocks for errors upon learning is a function of the conditions under which learning is measured. Whether the magnitude of the beneficial effects of shocks for errors is roughly of the same order when optimal conditions for each are employed, and whether the optimal conditions themselves, that is, the particular conditions as regards the

method of administering the shocks, intensity, etc., conducive to most efficient learning, are greatly different for rational learning from what they are for motor tasks, are questions beyond the scope of the present study.

5. Under the less difficult alphabetical order of presenting the letters, where the efficiency of learning was increased as the result of shocks, there was an increase in the time per trial and the time per response which probably indicates a more cautious attitude on the part of the subjects as the result of shocks for errors.

6. Further, since shocks for errors increased the efficiency of learning under the less difficult manner of presenting the rational learning problem and had a slight, but probably insignificant, detrimental effect under the more difficult condition, the results are consistent with those involving motor tasks, concerning the relationship between the optimal intensity of shock and the difficulty of the task being mastered, which indicate that the optimal intensity for simple problems probably lies closer to the maximum intensity end of the scale than is the case for difficult problems.

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References

1. Bunch, M. E., The effect of electric shock as punishment for errors in human maze-learning, *J. Comp. Psychol.*, 1928, **8**, 343–359.
2. Bunch, M. E., and McTeer, F. D., The influence of punishment during learning upon retroactive inhibition, *J. Exper. Psychol.*, 1932, **15**, 473–495.
3. Bunch, M. E., Certain effects of electric shocks in learning a stylus maze, *J. Comp. Psychol.*, 1935, **20**, 211–242.
4. Bunch, M. E., The amount of transfer in rational learning as a function of time, *J. Comp. Psychol.*, 1936, **22**, 325-337.
5. Cole, L. W., The relation of strength of stimulus to rate of learning, *J. Anim. Behav.*, 1911, **1**, 111–124.
6. Dodson, J. D., Relative values of reward and punishment in habit formation, *Psychobiol.*, 1917, **1**, 231–276.
7. Gilbert, R. W., and Crafts, L. W., The effect of signal for error upon maze learning and retention, *J. Exper. Psychol.*, 1935, **18**, 121–132.
8. Peterson, J., Experiments in rational learning, *Psychol. Rev.*, 1918, **25**, 443–467.
9. Yerkes, R. M., and Dodson, J. D., The relation of strength of stimulus to rapidity of habit formation, *J. Comp. Neurol. and Psychol.*, 1908, **8**, 475–491.

A COMPARATIVE STUDY OF THE RESPONSE OF NORMAL AND PATHOLOGICAL EARS TO SPEECH SOUNDS [1]

BY NOBLE H. KELLEY, PH.D.

I. BACKGROUND OF THE PROBLEM

Previous experimental observations have suggested that the relationship between intensity level and loudness in some types of pathological ears is different from that in the normal. The phenomenon may be stated as follows:

> Sound, at a given intensity level above threshold, elicits in the pathological ear an auditory sensation of loudness greater than that produced in the normal ear.

This phenomenon has been thoroughly investigated and defined by Reger (9). His study was concerned with abnormal ears that manifested normal thresholds for the lower but markedly raised thresholds for the higher frequencies. By means of a technique for equating loudness levels (equating the loudness of two pure tones which differ in frequency), data were obtained on the comparative loudness response of this particular type of ear to various sound frequencies. These data are presented graphically in the form of equal loudness level contours. In one ear investigated there is normal sensitivity from 64 to 2048 ~. At 4096 ~ the threshold is raised 70 db. Now in the case of the normal ear, as shown by Kingsbury (7) and Fletcher and Munson (1), a frequency of 4096 ~ at a given number of decibels above the threshold is judged as loud as a frequency of 2048 ~ at the same intensity level above threshold. Reger found, however, in the type of ear indicated above, that an intensity 10 db. above the raised threshold at 4096 ~ is judged as loud as a frequency of 2048 ~ at 45 db. above its threshold. From an investigation of several ears Reger concludes:

[1] This paper is the condensation of a doctorate thesis, directed by Dr. Scott N. Reger, Departments of Psychology and Otolaryngology, State University of Iowa.

"A given frequency a given number of decibels above the threshold of the hard-of-hearing ear results in a louder sensation of sound than does the same frequency the same number of decibels above the threshold of the normal ear.
The greater the hearing loss the louder the auditory sensation when the intensity is increased a given number of decibels above threshold.
The magnitude of the auditory sensation apparently increases more rapidly at intensity levels just above the threshold."

Information relative to the above phenomenon was first observed by Pohlman and Kranz (**8**) while investigating an ear which manifested a 'range of deficient acuity.' On stimulating this type of ear with a continuously variable frequency over the audible range at an intensity level 15 db. above the normal threshold, the observer heard no sound when the frequency presented was within the 'range of deficient acuity.' However, at an intensity level 10 db. above the maximum elevation of the threshold, the observer was no longer aware of this area. It seemingly disappeared completely.

Fowler (**3**) also observed the phenomenon in an investigation of 'marked deafened areas' in apparently normal ears. In an audiometric examination of a patient with normal hearing in the left ear, and with a normal threshold in the right ear except for a narrow frequency range near 4000 ~ where the threshold was raised 40 db., he noted that

"The loudness of tones (near 4096) of from 10 to 25 sensation units above the threshold of the left (non-affected) ear appeared the same loudness as 5 sensation units above the threshold of the right (affected) ear."

Guttman and Ham (**4**) from a series of experiments show that under certain conditions the relationship between intensity level and loudness in the pathological is different from that in the normal ear. Their observations, however, are limited to a situation in which the stimulating tone is presented only in the presence of a second or masking tone.

II. The Problem

The above observations suggest that pure tones at a given intensity level above the threshold result in a loudness response of greater magnitude in the type of pathological ear indicated above than in the normal ear. This study under-

took an investigation of the relationship of this phenomenon to the hearing of speech sounds. The procedure involved a comparative study of the auditory response of individuals, some with normal thresholds and others with raised thresholds due to pathological conditions of the ear, in regard to three psychological functions:

1. Intensity level preference for continuous discourse.
2. Intelligibility response to a configured group of words.
3. Articulatory recognition of vowel and consonant sounds.

III. Apparatus and General Procedure

Speech sounds presented to the observers were articulated by the experimenter and transmitted by a speech amplification system of high quality. This consisted of an R.C.A. velocity microphone, a pre-amplifier, a power amplifier, and a Western Electric moving coil or dynamic type receiver. The microphone and pre-amplifier were operated in a quiet room; the power amplifier and receiver were located in a neighboring sound-proof room. The maximum intensity level of speech amplified through the system was approximately 110 db. above the normal threshold. The intensity level of the sounds presented was controlled by means of accurate attenuators, calibrated directly in decibels. Frequent check showed that the gain and stability of the system remained constant throughout the testing procedure. The quality of the reproduced speech was highly satisfactory. At the intensity levels preferred by the normal observers as most natural and pleasing, there was practically 100 percent recognition of both vowel and consonant sounds. A second communicating system permitted conversation between the experimenter and the observer.

The observers with pathological ears were limited to those who had approximately equal decibel hearing losses over their audible frequency range. These observers were adults who had developed normal speech previous to auditory impairment. Since in some instances the audiograms of the two ears of the observers with auditory pathology were dissimilar, only monaural hearing was used throughout the experimentation. The thresholds of the normal observers selected did not deviate more than 10 db. from the normal curve of the audiogram as obtained with the Western Electric 2-A audiometer. The experimentation was repeated with the threshold of each normal ear artificially raised approximately 40 db. by occluding the ear with a mixture of white vaseline and paraffin (6).

IV. Intensity Level Preference

Intensity level preference is defined as that intensity level above the auditory threshold for speech sounds at which the observer prefers to listen to continuous discourse.

Thirty observers with normal hearing, thirteen observers with a hearing loss of from 40 to 50 db. over the audible range (designated as Type A), and nine observers with a hearing

loss greater than 60 db. (Type B) were used in the experimentation. Some of the observers in Type B did not hear the highest and lowest frequencies generated by the audiometer.

Each observer was asked to adjust the dial of the attenuator (calibrated in steps of 2 db.) to that loudness level where speech was judged as most natural and pleasing and neither too loud nor too soft. Two tests were made with each observer. In the second test the setting of the attenuator on the pre-amplifier was changed by the experimenter so that the preferred level would shift on the attenuator manipulated by the observer. Thus, the observer could not depend upon the reading of a previous observation. Observers with pathological ears were asked to increase the loudness of the speech to a level that would be considered as definitely too loud. The data secured from the above procedure are presented below.

TABLE 1

	Normal Ears Open	Normal Occluded	Abnormal Type A	Abnormal Type B
Mean preference level (db. above threshold)	38	38	23	20
Standard error of mean	1	1	1	1
Mean difference (1st and 2nd tests)	2	2	1	1
Mean level—'too loud' (db. above threshold)			38	28

It may be noted that an observer is very certain as to his preferred intensity level, the mean difference between the first and second trials being only two decibels.

It is evident that there is a marked difference between normal and pathological ears in regard to the *preferred intensity level.* The normal ear prefers to listen to amplified spoken discourse at a mean intensity level 38 db. above threshold; and these sounds may be further amplified to an intensity level 70 db. above threshold before they are judged as 'too loud.' In the pathological ear (Type A) the preferred intensity is at a mean level 23 db. above threshold, and sounds 38 db. above threshold (the level preferred by the normal ear)

are judged as definitely too loud. Again, in pathological ears (Type B), where the threshold was raised from 60 to 90 db., the preferred level was only 20 db. above threshold, and speech sounds 28 db. above threshold were judged as decidedly too loud. Three of these observers, who had hearing losses of 75, 85, and 90 db., preferred to listen to spoken discourse at an intensity level 16, 17, and 14 db. respectively above threshold. At these levels the observers had clear and distinct recognition of the continuous speech to which they listened. In other words, the greater the hearing loss the less the intensity above threshold are both the preferred intensity level and the level at which sounds are judged as too loud.

When the threshold of the normal ear is artificially raised 40 db. by occlusion, the preferred intensity level still remains at 38 db. above the raised threshold. This indicates that the occluded ear is functionally different from a pathological ear. In the case of occlusion the sound is obstructed at the entrance to the external meatus, thus raising not only the auditory threshold but also the threshold of feeling. The sound intensity here operating on the tympanic membrane and middle ear mechanism is only 38 db. above threshold as was the case with the normal ear open. Whereas, in the pathological ear, the intensity operating on these structures is greater by the extent to which the threshold is raised. Consider the case of a pathological ear, with the threshold raised 40 db., and the intensity level of speech sounds at 38 db. above this raised threshold. The sound energy operating on the middle ear mechanism in this particular circumstance is equivalent to that at an intensity level 78 db. above the threshold of a normal ear. It is possible that the observers with pathological ears were selecting a lower preferred intensity level because of extra-auditory stimulation due to the additional energy load on the middle ear. All these observers evidenced binaural impairment. This precluded any normal reference for loudness that might serve as a standard in estimating the relative loudness of spoken discourse in the abnormal ear.

An investigation of the preferred intensity level in abnormal ears in persons with the opposite ear normal is now in progress. In these cases, the observer can compare the loudness response of the pathological ear directly with that in the normal ear. Other pathological ears in which the tympanic membrane and the ossicles have been removed are also being studied. Preliminary results on two cases seem to indicate that the preferred intensity level, in abnormal ears with the tympanic membrane and ossicles removed, is the same as that in the normal ear. This would suggest that extra-auditory sensation due to the presence of an affected middle ear apparatus might favor the selection of a much lower preferred intensity level. Loudness comparison in the normal and abnormal ear of the same observer also seems to indicate that spoken sounds at given intensity levels above the threshold of either ear are approximately equal in loudness.

V. Intelligibility Response

Since in abnormal ears the preferred intensity level for continuous discourse was much lower than in normal ears, a further comparative investigation was made in regard to the recognition of speech sounds. *Intelligibliity response* was the first level of recognition studied. This function is defined as the ability of a person to grasp the meaning contained in a configured group of words. Measurement was made with a list [2] of sentences of the interrogative and imperative type, each containing a simple idea.

Thirteen observers with normal hearing and eleven observers with a hearing loss of from 40 to 50 db. were used in this division of the study. The intelligibility response was measured at intensity levels 2, 4, 6, etc. db. above threshold and the data are presented graphically in Fig. 1. An examination of the values indicates that there is little difference between the intelligibility response of normal and pathological ears of the type investigated. Intelligibility begins at six decibels above threshold and reaches a value of 90 percent

[2] Samples of tests used in the investigations reported in this paper and more detailed data are appended to the Ph.D. thesis of the writer (5).

at 14 and 16 db. above threshold. The standard error of the mean values plotted in Fig. 1 was two percent or less.

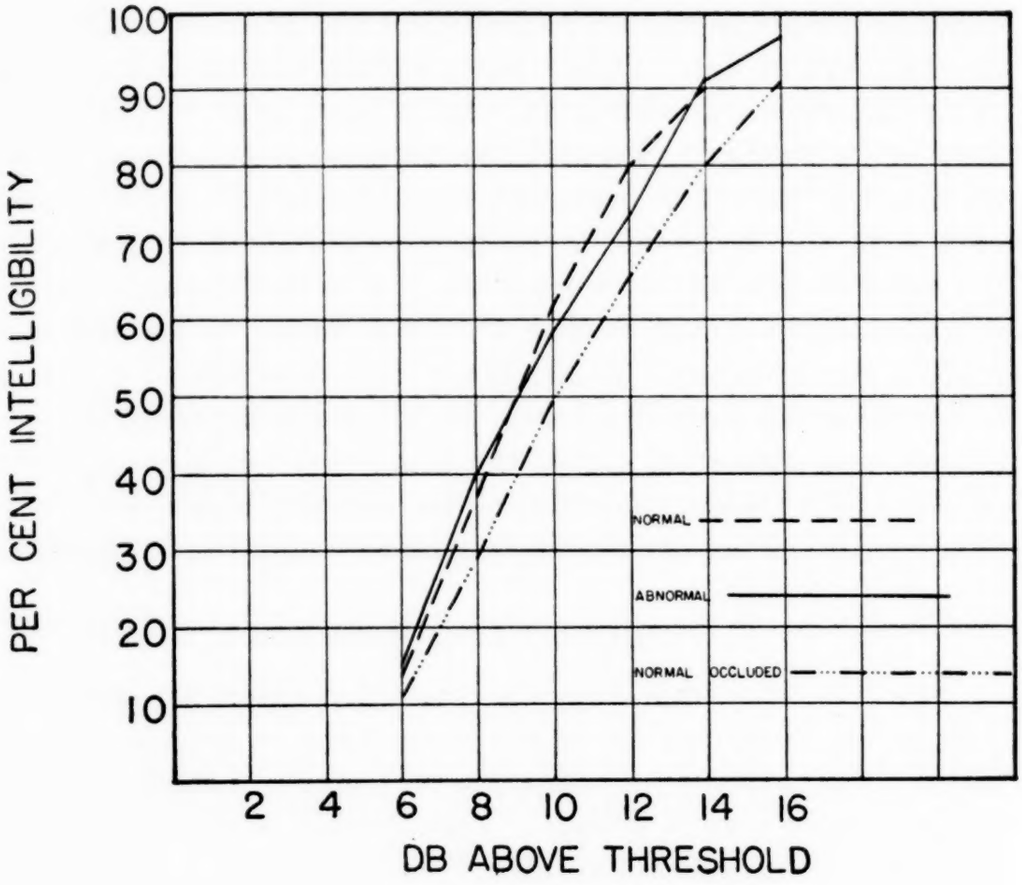

FIG. 1.

VI. ARTICULATORY RECOGNITION

Articulatory recognition is defined as the ability of a person to recognize vowel and consonant sounds as they appear in monosyllabic words. Measurement was made with a test list of 75 words. Several lists were used, each containing the same words but in a different arrangement. One sound only was graded in each word. Each list contained 25 vowel and 50 consonant sounds. This arrangement facilitated the conversion of the data into percentage values. Two lists or 150 words were presented at each intensity level measured.

The same observers who were used in the study on intelligibility served in this experimentation. Articulatory recognition was measured at various intensity levels above

threshold. Since Reger (**9**) had concluded that loudness in the pathological ear increases more rapidly at intensity levels just above the threshold, an attempt was made to explore thoroughly the intensity range from two to eight decibels above threshold. Other samplings were made at higher levels. The mean percentage values are plotted in Fig. 2 for the various intensity levels investigated up to 26 db. above threshold. The standard error of these mean values ranged from one to three percent.

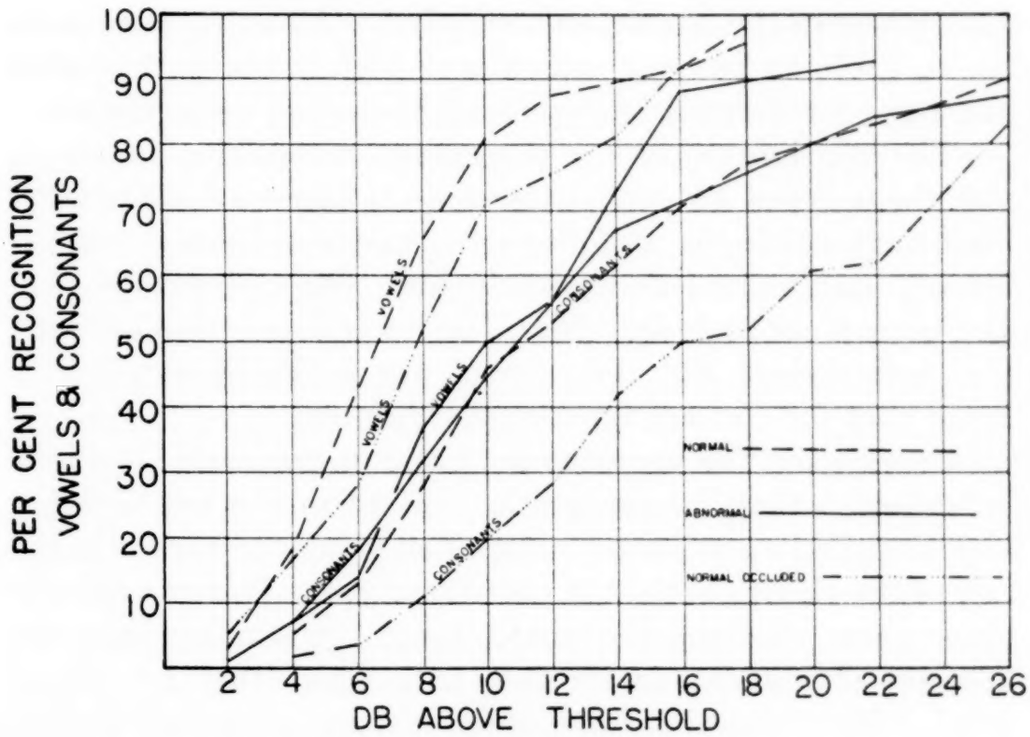

FIG. 2. Articulatory recognition.

In the recognition of vowel sounds, the normal ear is the most efficient; the normal occluded ear is more efficient than the pathological ear. In the recognition of consonant sounds, the pathological and the normal ears are approximately equal, and are superior to the normal occluded ear. Individuals with normal ears and with the normal ear occluded recognize vowel more readily than consonant sounds. But in the case of pathological ears the consonants are recognized with practically the same facility as are the vowels.

An analysis was made in regard to the frequency with which each sound was recognized. A comparison of the order ranking for each type of ear reveals certain disparities. The vowels o (balk) and u (book), which rank at the top of the list in the case of the normal and in the case of the normal occluded ear, drop to 20th and 26th places in the pathological ear. The vowel e (beak), which ranked 25th and 19th in the normal and normal ear occluded, ranks eighth in the pathological ear. The consonant s has the highest recognition value in the pathological ear, ranks seventh in the normal, but drops to 32nd place in the normal ear occluded. Also the consonants sh, st, t, ch, and j (jen), which rank high in the pathological ear, have low recognition value in the normal ear occluded.

The relationship of the percentage recognition values in the three types of ears, expressed in terms of correlation coefficient values, is as follows: normal and normal ear occluded, .94; normal and pathological, .80; and pathological and normal ear occluded, .66. The lower correlation between the pathological and the normal ear occluded emphasizes again that the two are functionally different.

Considering the phenomenon basic to the study, it might be expected that the recognition values in the *intelligibility response* and in *articulatory recognition* would be higher in the case of the abnormal than in the normal ear. It is an ordinary observation that there is some direct relation between the loudness of sounds and the ease with which they are recognized. However, there are other factors in operation here that indicate that the above expectation is not warranted. Recognition depends not only upon the loudness with which speech sounds are heard but also upon the perception of the important component frequencies involved in that speech. Fletcher (**2**) has stated that the intensity range of sound frequencies in ordinary discourse is approximately 30 db. Now, if the speech sounds presented are only 10 db. above the threshold, it is apparent that only those frequencies in the upper part of the intensity range are above the threshold. Other important frequency components are below the limen and cannot contribute toward recognition. It is possible for

those frequencies that are above threshold to be louder in the abnormal than in the normal ear and yet be no more easily recognized because component frequencies important for recognition are not psychologically present.

VII. Conclusions

1. The preferred intensity level and the intensity level above threshold at which continuous discourse was judged as too loud were lower in the pathological than in the normal ear. The greater the hearing loss, the smaller these values were.

Individuals with normal ears preferred to listen to spoken discourse at a mean intensity level 38 db. above threshold. Individuals with pathological ears (Types A and B) preferred the same speech at mean levels 23 and 20 db. above threshold.

2. The intelligibility response in the case of the pathological ear was similar to that of the normal ear.

Intelligibility begins at six decibels and attains a value of 90 percent at 14 db. above threshold.

3. In the recognition of vowel sounds, the normal were more efficient than the pathological ears. In the recognition of consonant sounds, the normal and the pathological ears were approximately equal.

Individuals with normal ears recognized vowel more readily than consonant sounds. Individuals with pathological ears recognized consonant and vowel sounds with practically the same facility.

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References

1. Fletcher, H., and Munson, W. A., Loudness, its definition, measurement and calculation, *J. Acous. Soc. Am.*, 1933, 5, 82.
2. Fletcher, H., Can we scientifically advise patients as to the effectiveness of hearing aids?, *Ann. Otol., Rhin. & Laryng.*, 1932, 41, 727.
3. Fowler, E. P., Marked deafened areas in normal ears, *Arch. Otolaryng.*, 1928, 8, 151.
4. Guttman, J., and Ham, L. B., Masking effects of an interfering tone upon a deafened ear, *J. Acous. Soc. Am.*, 1930, 2, 83.
5. Kelley, N. H., A comparative study of the response of normal and pathological ears to speech sounds, *State University of Iowa Thesis*, 1936.

6. KELLEY, N. H., AND REGER, S. N., The effect of binaural occlusion of the external auditory meati on the sensitivity of the normal ear for bone conducted sound, *J. Exper. Psychol.*, 1937, **21**, 211–217.
7. KINGSBURY, B. A., A direct comparison of the loudness of pure tones, *Phys. Rev.*, 1927, **29**, 588.
8. POHLMAN, A. G., AND KRANZ, F. W., Binaural minimum audition in a subject with ranges of deficient acuity, *Proc. Soc. Exper. Biol. and Med.*, 1924, **21**, 335.
9. REGER, S. N., Differences in loudness response of the normal and hard-of-hearing ear at intensity levels slightly above the threshold, *Ann. Otol., Rhin. & Laryng.*, 1936, **45**, 1029.

BRAIN POTENTIAL STUDIES OF PERSEVERATION: II. PERSEVERATION TIME TO VISUALLY PRESENTED WORDS

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For the purposes of this study we wish to make the following assumptions: (1) at any given moment, brain potentials reveal the patterning of the functional organization of the cortical cells; (2) the patterning and consequently the brain potentials change with stimulation; and (3) in point of time there is not a one-to-one relationship between the stimulus and the patterning of cortical organization; *i.e.*, the removal of the stimulus may leave the patterning resulting from the stimulus or variations of that patterning still functioning so that it may take some time before the pre-stimulus patterning is restored. Since perseveration is usually defined as the temporal after-effect of a stimulus, in the present study its duration will be considered as the length of time between the removal of the stimulus and the return of the brain potentials to their pre-stimulus value.

In the first study of this series,[1] we found the mean perseveration time to a 150-watt light to be 0.98 sec. (N = 1002). During the course of repeated presentations of the light the perseveration time decreased markedly. We called this adaptation.

In this second study we measured the perseveration time to 20 words, 20 nonsense words, and 10 blank cards. The words, drawn from Wells' free-association list, included 5 neutral, 5 emotionally colored, 5 'double-barreled,' and 5 'opposites' words. The nonsense words were constructed from the words by rearranging the letters of each so that the physical intensity of the light reflected from the card bearing a word and from a card bearing that word's nonsense combination of letters was the same. This made it possible to compare the perseveration times of words and their nonsense letter combinations without introducing the variable of changed intensity which influences

[1] L. E. Travis and J. R. Knott, Brain potential studies of perseveration: I. Perseveration time to light, *J. Psychol.*, 1936, 3, 97–100.

perseveration time.[2] The blank cards were of the same type as those used for projecting the words and combinations. Since they were without black letters they reflected a light of slightly higher intensity than the lettered cards.

The stimuli were projected upon a translucent screen. Each stimulus had an objective time value of approximately 0.25 sec. Except that a nonsense combination was never adjacent to the word from which it was derived, the cards were presented in chance order.

For recording the brain potentials, standard amplifiers were used to drive a Boehm 2-A ink-writing undulator which responded up to 30~. The potentials were led off by means of surface electrodes, one attached to the scalp over the left occiput and the other to the lobe of the left ear.

Each of the subjects (5 normal adults) sat in a comfortable chair in a dark and quiet room. The viewing screen was at a suitable elevation and 3 or 4 feet in front of the chair. The subjects were instructed to maintain a passive attitude toward each stimulus and to make no effort to accelerate or inhibit any associations which might be aroused by it. At the end of an experiment, a general report was obtained from each subject with respect to his reactions to the stimuli.

The data are presented in Tables I and II. The perseveration times obtained in this study are much longer than that obtained previously by us. It is, however, of particular interest to note that within the conditions of the present

TABLE I

PERSEVERATION TIME VALUES (IN SEC.) FOR THE THREE TYPES OF STIMULI

	AM	SD	Range	N
Words	4.6	3.3	0.6–15.9	93
Nonsense words	4.8	3.2	0.6–16.2	98
Blank cards	3.1	2.1	0.4– 7.0	47

TABLE II

SIGNIFICANCE OF DIFFERENCES BETWEEN THE MEAN PERSEVERATION TIMES FOR THE THREE TYPES OF STIMULI

	Diff. in Sec.	CR
Words vs blank cards	1.5	3.4
Nonsense words vs blank cards	1.7	4.0
Words vs nonsense words	0.2	0.5

[2] H. H. Jasper, Cortical excitatory state and synchronism in the control of bioelectric autonomous rhythms, *Cold Spring Harbor Symposia on Quantitative Biology*, 1936, 4, 320–338.

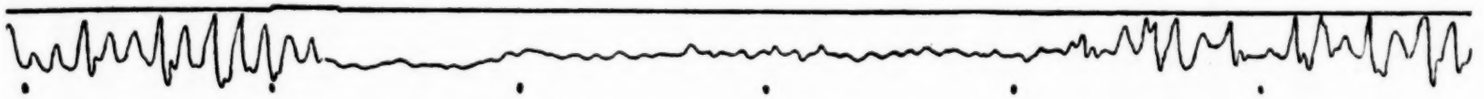

FIG. 1. Record showing the depression of the brain potentials by the visual presentation of the word 'black' and their re-establishment following the withdrawal of the stimulus. Displacement of signal line at top gives length of time word was shown. Time intervals in sec. marked off at bottom. Perseveration time equals length of time elapsing between the disappearance of the stimulus and the full return of the brain potentials. In this record it was read as 3.1 sec.

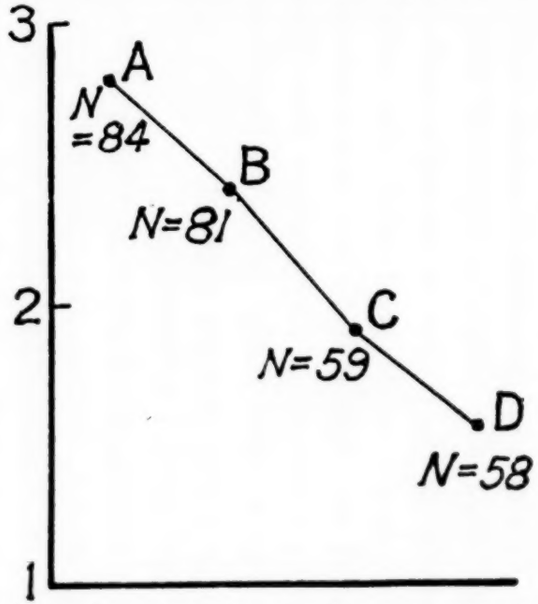

FIG. 2. Adaptation to repeated presentations of the two words, a neutral and an emotionally colored one. Ordinate scale = time in sec. *A* = mean perseveration time for first half of records for neutral word; *B*, for second half of records for neutral word; *C*, for first half of records for emotional word; and *D*, for second half of record for emotional word.

study the words and nonsense combinations gave greater perseveration times than blank cards (Table II), the stimuli of highest intensity. From the standpoint of intensity alone the blank cards might have been expected to give a longer perseveration time.

There are at least two possible explanations of this finding. One is that it is a matter of a structured versus an unstructured visual field. The other is that meaning was attached to the visual field produced by the words and nonsense words with a related repatterning of the cortical functional organization which was more extensive in space-time than the repatterning related to the visual field produced by the blank cards. The second possibility seems to be the more reasonable one since the subjects reported that they had various types of imagery, trains of thought and, in some instances, affective states associated with the words and that they attempted to 'figure out' the nonsense words. The blank cards gave a longer perseveration time than the simple light used in the former study probably because they called forth frequently a questioning attitude. The subjects 'wondered' if they had missed something.

The problem of adaptation enters into our discussion. In the first study, during the course of repeated presentations of the light, the perseveration time decreased significantly. In the present study, no such phenomenon was noted for the 50 stimuli as a series. A decrease was noted, however, for the 10 blank cards in that the mean perseveration time to the first card, 4.8 sec., was rarely equalled and never exceeded by the perseveration time to any of the subsequent 9 cards. The mean time for the 9 cards was slightly over 2 sec. The subjects reported that particularly for the first blank card in the series, they thought they had 'missed the word.' As the blank cards continued to appear the subjects realized what was happening and became more or less adapted to them.

Pursuing this question of adaptation further, we presented repeatedly to each subject first, a neutral word such as *light;* and second, an emotionally colored word such as *kill.* The results are given in Fig. 2 and Table III. They indicate that

with repeated presentations a word loses its perseverative value. This held true even if in the middle of a long series of presentations the word was changed from a neutral to an emotionally colored one. It was found, however, that the introduction of the second word did retard momentarily the course of adaptation. The mean perseveration time for the last five presentations of *light* was 1.8 sec.; and for the first five presentations of *kill*, 2.4 sec. Statistically, there is not a significant difference between these means (CR = 1.2). Nevertheless, it may be stated that the introduction of the

TABLE III

ADAPTATION TO REPEATED PRESENTATIONS OF TWO WORDS, A NEUTRAL AND AN EMOTIONALLY COLORED ONE

	Diff. in Sec.	CR
First half neutral vs second half neutral	0.33	1.05
Second half neutral vs first half emotional	0.56	2.08
First half emotional vs second half emotional	0.24	0.91
First half neutral vs first half emotional	0.89	3.29
Second half neutral vs second half emotional	0.80	2.61
First half neutral vs second half emotional	1.13	3.67

new word in the series retarded the adaptation rate. This statement has support in the comparison between the perseveration time for the last presentation of *light* and that for the first presentation of *kill*, 1.3 and 3.3 sec. respectively.

Because, with both a relatively meaningless light stimulus and a word, repeated presentations produced within the time limits of our experiments an ever decreasing duration of disturbance of the brain potential pattern, adaptation seems related solely to the element of repetition. This conclusion is supported by the lack of adaptation occurring in the regular series of 50 stimuli as a whole (adaptation did occur in relation

to the blank cards). Here the element of change rather than the element of repetition was the more effective.

In summary, it is tentatively concluded that psychological events have a physiological basis revealed in the brain potentials. Therefore, the psychological events associated with the phenomenon of perseveration can be studied with the brain potential technique, perseveration time being detectable by changes in the potentials. Perseveration time thus measured was found to be 4.6 sec. for standard words having a known meaning; 4.8 sec. for nonsense words having no known meaning; and 3.1 sec. for a light field of slightly higher intensity than that reflected from the word-cards.

Adaptation does not occur when the stimulus is changed at each exposure. Adaptation does occur when the stimulus is not changed and a large number of exposures is made.

On the basis of the data it is tempting to say that 'meaning' has a physiological basis detectable by the brain potential technique, since the meaningful and nonsense (but still meaningful) words were associated with longer perseveration times than light.

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THE STARTLE PATTERN IN CHILDREN AND IDENTICAL TWINS [1]

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Investigation of the startle pattern has shown it to be present in human infants [2] and adults.[3] The purpose of the present study is to complete the genetic picture by investigating its presence in children. It was decided to include a group of identical twins among the subjects. Since we have a basic, universal response in the startle pattern, it was felt that an examination of any differences or similarities in response between members of a pair of identical twins would shed further light, not only upon the startle pattern itself, but upon the mutual resemblances of such twins.

Procedure

Thirty-four children, ranging in age from three to fourteen years, served as subjects. Twenty-three of them were males, eleven were females. Included were ten pairs of identical twins, ranging in age from three to twelve years old. Nine of the pairs were male and one was female. The children were photographed against a special photographic screen with the camera running at a speed of sixty-four frames per second. The stimulus was the firing of a .22 caliber blank cartridge. The pictures were projected in slow motion at a speed just above the flicker point, and were scored by a committee of three persons. A more elaborate description of the technique may be found elsewhere.[4]

Results

The typical startle pattern consisting of head movement, lid reflex, characteristic facial expression, hunching of the shoulders, abduction of the upper arms, bending at the elbows,

[1] This study from the psychological laboratory of Connecticut College for Women was made possible by a National Research Council grant to one of the authors. The assistance of Edna B. Hunt and Mildred McGourty in all phases of the work is gratefully acknowledged.

[2] Hunt, W. A., Clarke, F. M., and Hunt, E. B., Studies of the startle pattern: IV. Infants. *J. Psychol.*, 1936, 2, 339–352.

[3] Hunt, W. A., Studies of the startle pattern: II. Bodily pattern. *J. Psychol.*, 1936, 2, 207–213.

[4] *Ibid.*, p. 207.

pronation of the lower arms, clenching of the fists, forward movement of the trunk, and bending at the knees was found in all the subjects. Because it was impossible to photograph the children in bathing suits we could not observe the typical contraction of the abdomen. It would seem safe, however, to infer its presence. While the reactions range from strong to slight, the characteristic response is quite marked, and stronger than is found in adults. Although the range of response, from strong to slight, renders judgment difficult, there seems to be a tendency for the response to diminish with increasing age. While one cannot say that there is *more* response in the children than in infants, the pattern in the children is more regular, with much less opposed movement than in infants. This may be a function of posture, since the infants were photographed lying down and the children standing up, but it seems more logical to attribute it to the difference in neural development and organization. As is true of adults, the child sometimes reacts more strongly to the second shot than to the first. In one child, we have an increasing response extending over the course of three stimulations. Gradual habituation with succeeding shots, however, is the general rule. Secondary movements following the startle response are more prominent among the children than among adults. In the younger children, these are usually of fear and flight, while in the older children more or less stylized, conventional responses indicating amusement, surprise, or distaste are the rule.

Negative movements were frequent in the lower arms, but did not appear in any other portion of the body. Pronation of the lower arms has consistently and definitely established itself as the least stable part of the pattern. This matter is receiving further investigation to ascertain the possible influence of postural tonus upon the irregularity of pronation.

Included among the subjects were two colored children. Since no mention has been made in previous studies of the occurrence of the pattern in other races than the white, and since its appearance in other races would furnish further indication of the universality of the response, we may well

summarize our material on that subject here. In addition to the two children just mentioned, we have unpublished data on three normal adults. To this we may add the data obtained in the previous study of infants and a study of abnormal subjects,[5] many of whom were colored. The startle pattern is found in colored subjects without exception. The range of response is the same as in whites, and no racial differences appear. This gives us further proof of the universality of the response.

In the case of our ten pairs of identical twins, we found consistent differences in the response between members of a pair of twins. In three pairs, this difference was so marked as to include not only the amount of movement in each element of the pattern, but also the number of elements appearing. Typical are Dick and Bob, age five years. Bob responds with the complete pattern, while Dick shows only lid reflex, head movement, slight abduction of the upper arms, and bending at the right elbow. In seven pairs, all elements of the pattern are present in both members, but the amount of movement is noticeably larger in one of the children. These nine pairs showed the same tendency upon repetition of the shot three minutes after the first stimulation. The child who had jumped more at the first shot also jumped more at the second. In one pair, the response seemed to be equal, but upon a second and third repetition of the stimulus, one member of the pair showed a consistently greater response.

In view of the basic nature of the startle pattern and of the strong resemblances usually found between the members of a pair of identical twins, this quantitative difference in the startle pattern was somewhat unexpected. The question of the possible correlates of this difference immediately arose.

The tendency of the members of a pair of identical twins to differ in handedness, one being right-handed while the other is often left-handed, suggests that this may enter as a factor. In our ten pairs of twins this difference in handedness was quite clear in four. Three more pairs were tested carefully

[5] Landis, C., and Hunt, W. A., Studies of the startle pattern: VII. Abnormals. *J. Psychol.* In press.

and a clear tendency to confuse was found in one member of each pair.[6] Among the tests used were the Van Riper angle board and the Jasper test for phi.[7] Of the remaining three pairs, two were too young to cooperate on the tests and the other was not available for further study. This gave us seven pairs of twins in each of which one member was either clearly left-handed or partially so. In every one of the seven pairs the greater startle pattern was shown by the twin with left-handed tendencies. This indicates that the amount of the startle response may be tied up with the problem of cortical dominance, since those twins showing confusion or mixed dominance gave in every case the greater response. Such a connection might well be effected through the mechanisms of cortical release. In view of the present ambiguity surrounding the entire question of cortical dominance, however, any theoretical suggestions would best be deferred at this time.

Summary

The startle pattern is present in children. Both the primary pattern and the secondary movement are greater than in adults. The pattern is found equally clearly in the Negro race. Members of a pair of identical twins differ in the amount of their responses. In every case where tests for handedness were given, the twin showing the larger startle response showed mixed dominance, with some tendency to be left-handed.

(Manuscript received February 25, 1937)

[6] Thanks are due Dr. H. H. Jasper and Mr. E. T. Raney for their assistance in personally administering these tests.

[7] Jasper, H. H., A laboratory study of diagnostic indices of bi-lateral neuromuscular organization in stutterers and normal speakers. *Psychol. Monog.*, 1932, **43**, 72–174.